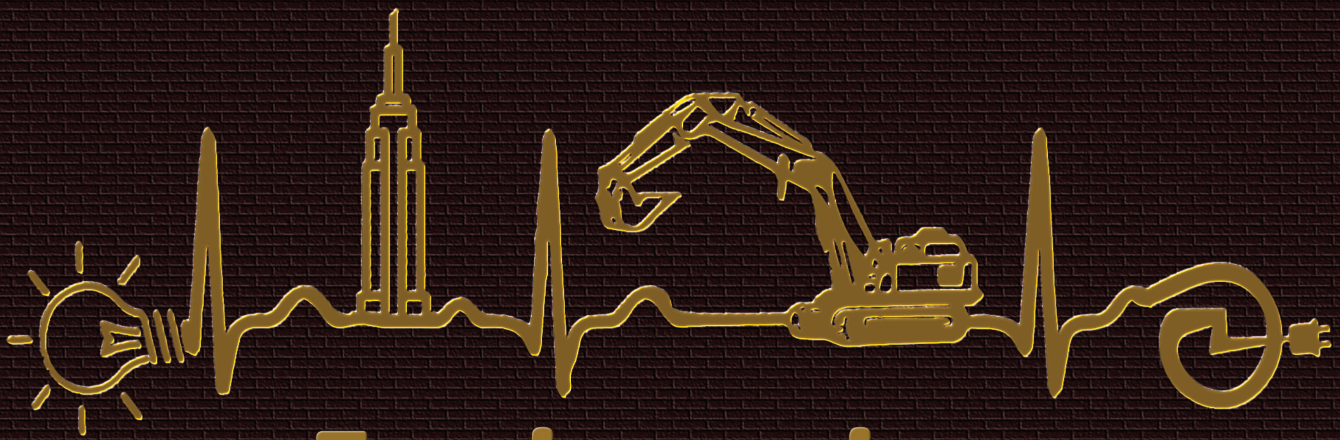
The Institution of Engineers (India)



Engineering for the Future

– an IEI Centenary Publication

Interdisciplinary Coordination Committee

IEI Centenary Publication

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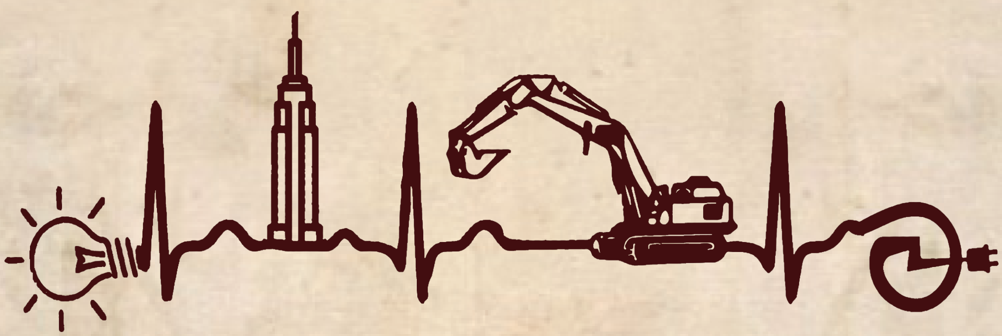

Engineering for the Future

Editor

Shri Pradeep Chaturvedi, FIE, FNAE

Chairman, Interdisciplinary Coordination Committee

The Institution of Engineers (India)

FOREWORD

It is a rare privileged for me to put across my view on this book 'Engineering for the Future' alongside with the doyens in the field of engineering and it also provides me with a rare opportunity for a reality check and align my vision based on the repertoire of information shared through this impressive volume packed with nuggets of knowledge. As the constitutional head of this august body of professional engineers, it is my solemn duty to highlight and bring to fore the plethora of opportunities and possibilities related to the profession of engineering that have been extensively covered in this book.

The release of this book could not have come at a better time when The Institution of Engineers (India) is all set to commence its journey beyond hundred years. Having achieved the objectives set by our founding fathers, it is now time for the Institution to envisage and plan for the century ahead. As we are all aware, there is a tectonic shift in the way technology is being leveraged to spread into every aspect of human life. This demands that engineers need to act and equip themselves with agility to remain relevant and be able to contribute to the developmental needs of society. While traditional engineering education will necessarily be required to lay a strong foundation in basic engineering principles and skills, there will be an imperative to constantly upgrade and imbibe new skills, attributes and technology. These aspects have found a comprehensive coverage in this special centenary volume. Besides, the evolving engineering paradigm, as discussed in this volume, increasingly calls for engineers to consider the whole spectrum of sustainability i.e. from the economic, environmental, social and time dimensions. Further, the book incorporates contribution from policy makers who have discussed how congruent policies can be framed and retrofitted to support sustainable engineering practices and encourage self reliance.

Standing at the crossroads of a century of glorious existence, it was felt appropriate to bethink, introspect and document the story of engineering and the promises it hold in days ahead has culminated into this volume. This volume based on facts, figures and miscellany, is a repository of events, data and records and provides roadmap to achieve pertinent sustainable development goals through affordable, equitable and indigenous engineering solutions.

I am indebted to the Council for rendering constant support and cooperation in bringing out this informative volume and also appreciate the Interdisciplinary Coordination Committee members for their active involvement. The curation of the book has been immaculate right from content to contributors and indicates immense dedication and ardor from the entire editorial team. This book will serve as an anthological reference bringing to the fore the rich legacy of the engineering profession and will serve as an ideal reference for the technical fraternity.

Er Narendra Singh, FIE
President, The Institution of Engineers (India)

PRELUDE

The last decade concluded with the pandemic of COVID-19 and has stymied the global economy which is yet to recuperate. Addressing the sustainable goals through engineering/technology interventions based on the essence of reconciling humanity with nature needs to be pursued earnestly to salvage the lost ground.

Engineering shapes the world we are living in and the future we are relying on. The goal is to make the orientation of engineering more professional, inventive, adaptive as well as indispensable, so that engineering could create a healthy and sustainable future of our world and the planet. This demands that engineers absorb the technology revolution to remain relevant and shoulder the responsibility in implementing of the United Nations' Sustainable Development Goals, which are the foremost needs of the society. Important innovations are on the horizon in a host of fields, including water, energy, medicine, transportation, communication, environment, material, data, robotics, and artificial intelligence. Engineers will play a key role in inventing the technologies of the future while keeping high standard of ethics. Engineering should be practical on fielding disruptive technologies, the user perspective and how strategic it is towards reorganizing a company's goals. The utility of adopting new technology is to be assessed based on its usefulness, inclusiveness, effectiveness, accessibility, environmental impact and opportunity and not attempting to fix the wrong problem. All of these requires improved engineering education and strengthened engineering capacity building, and increase the number of qualified engineers with right skills.

This book on 'Engineering for the Future', published as one of the centenary publications by the Institution of Engineers (India), provides a comprehensive technological route map. The selection of the topics, authors, intended outcome and the curation of the entire content was done in an extremely professional manner which speaks about the effort put in by the team. This excellent rendition has resulted in a classical yet perceivable volume which is a must read.

Prof Dr GONG Ke
President
World Federation of Engineering Organizations (WFEO)

PREFACE

The Institution of Engineers (India) has completed its 100 years of glorious existence contributing to national development. The Institution was established to fulfill the need for trained technical manpower to contribute in national development. The country is now passing through a stage where rapid economic development through use of latest technologies and skilled manpower is being stressed by the government. The Institution, since its inception, has brought pronounced melioration in scientific and technical arena that have resulted in advancement of engineering and engineering science and their application in India and facilitated the exchange of information and ideas on those subjects amongst the stakeholders.

Underlining the importance of the profession of engineering, the Institution, as corporate body, embarked upon various initiatives to frame a decisive roadmap to arrive at authoritative opinions on socially contextual engineering problems as enshrined under UN Sustainable Development Goals. To this end, the Interdisciplinary Coordination Committee of the Institution decided to come up with a special centenary publication titled "Engineering for the Future" with contribution from eminent personalities engaged in the profession of engineering. This book is aptly titled since it brings to forefront the significance and challenges of the engineering profession as the country needs to progress economically, socially and technologically in the next century.

The book provides a comprehensive coverage of all the future challenges and opportunities in the profession of engineering ranging from embracing sustainability and trans-disciplinary approach in developmental process; affordable housing for booming urban population; coping with demands for energy, drinking water, clean air, transportation, and reclamation of waste; globalization of engineering practices, restructuring engineering education in form and content; greater involvement of engineers in national policy framing; to name a few.

This book on 'Engineering for the Future' celebrates the exciting roles that engineering and engineers will play in addressing societal and technical challenges; up-skilling engineers to be leaders and able to balance the gains afforded by new technologies with the vulnerabilities created by their by-products without compromising the well-being of society and humanity; reflect and celebrate the diversity of all the citizens in our society. It emphasizes the fact that we, the engineers, must prepare for a new wave of change and can contribute meaningfully only if we are able to continue to adapt to new trends and educate the next generation of students so as to arm them with the tools needed for the world as it will be, not as it is today.

In a nutshell, this book is a definitive guide to the practice and profession of engineering enumerating new roles for engineers documented in an exemplary and engrossing manner.

Prof (Dr) Swapan Bhaumik, FIE
Chairman
Committee for Advancement of Technology and Engineering (CATE)

OPENER

The profession of engineering, beyond its technicalities, may be viewed as an all pervasive ageless impetus ushering technological evolution incrementally as well as incessantly punctuated by breakthrough and landmark achievements benefitting people and the planet. Engineering, irrespective of time, has evolved based on the needs of the masses empowering them technologically and will continue to act as a scaffold for emerging need-driven technologies in future.

The Institution of Engineers (India), which is celebrating its Centenary as always focused on engineering for the benefit of the society. COVID-19 Pandemic has stimulated extraordinary collaboration between our research laboratories and industry; and between industry and society. This has resulted in rapid action in arriving at a satisfactory solution for COVID-19 and the engineering solutions are now required for speedy distribution and administration and its emergency use. This situation has brought together engineers, biomedical professionals and the healthcare personnel to serve the society in a better manner through appropriate engineering solutions. That gives an indicator to identify various tenets for the future. The Institution of Engineers (India) advocate technical endeavours which are holistic, economic and lead to integrated approach for the society centered solutions. Keeping this in view the Centenary Book is being published with the theme: Engineering for the Future and focusing on what all needs to be done in different sectors of development to attain Sustainable Development Goals by 2030.

Engineering for the Future is a global effort that requires engineers to develop opportunities to link their efforts with the global development goals inspite of the global disruption due to COVID-19. The exercise of Engineering for the Future should be intented to provide a framework wherein technology and engineering will focus on human centric development. Many of the key attributes of engineers in 2030 will be similar to those of today but made more complex by the impact of new technology and need for sustainability. The pace of technological innovation will continue to be rapid and accelerating in the post COVID-19 situation. The world in which technology will be deployed will be intensely globally interconnected. The presence of technology in our everyday lives will be seamless, transparent, and more significant than ever. Engineers in future will have to posses strong analytical skills and will have to continue upgrading from time-to-time. Creativity will be an indispensible quality for engineering. The creativity requisites for engineering will change only in the sense that the problems to be solved may require synthesis of a broader range of interdisciplinary knowledge and a greater focus on systemic constructs and outcomes. Communication skills will be important for enhancing good engineering. The engineering fraternity will have to assist the leadership with their contribution in the national development

The future of engineering will essentially evolve around the tenets of sustainability, affordability, inclusivity, trans-disciplinary approach and most importantly employ indigenous technology and material in line with our quest for a becoming a self-reliant nation. To realize this, the engineering education and its delivery need to be reworked and the contemporary technologies can then be vectored in so as to have a ready pool of skilled engineers and entrepreneurs.

OPENER

The Interdisciplinary Coordination Committee (ICC) of The Institution of Engineers (India), pursuant to its decision, has rolled out this special volume on ‘Engineering for the Future’ on identified areas enumerated under the SDGs and congruent with the aspiration of the emergent economies as a tribute from this august body to the profession of engineering. With the right blend of contribution from eminent practicing and professional engineers, scientists, academicians and policy makers the volume is one of the most comprehensive, authoritative and up-to-date work in recent times. In bringing out this special centenary volume, we have ensured that selection of topics, mapping them with authors’ domain of expertise and curation of the entire content was done in an extremely professional manner so that we have an impressive range of articles.

I would like to summon all my gratefulness while putting on record the cooperation, support, involvement and patronage received from President IEI, Council, and Interdisciplinary Coordination Committee members right from conceptualization to publication of this book. Most importantly, I am indebted to all the authors for their laudatory effort through contribution of well-researched, well-documented articles and consider myself enriched being a part of this delightful exercise.

Shri Pradeep Chaturvedi, FIE, FNAE
Chairman, Interdisciplinary Coordination Committee
The Institution of Engineers (India)

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Engineering for the Future

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Shri Shekhar Dutt, SM, IAS (Retd)
Former Governor of Chhattisgarh

Author's Profile

Shri Shekhar Dutt started his career in 1967 with Indian Army and was awarded Sena Medal for Gallantry in the 1971 Indo-Pak War. He then joined the Indian Administrative Service in the M.P. cadre. As Principal Secretary of School Education, Sports and Youth Affairs in M.P. he introduced the Education Guarantee Scheme and the 'Shiksha Karmi Bharti Niyam'.

Shri Dutt, as Director General of Sports Authority of India, was responsible for India's stellar performance in the Manchester Commonwealth Games 2002. As Defence Secretary (2005-2007) of India he heralded modernization and probity in Defence Procurement. After retirement he became Deputy National Security Advisor (Aug 2007- Jan 2010) overseeing the Strategic Defence as well as National Security.

Shri Dutt assumed the office of the Governor of Chhattisgarh in Jan 2010 and was Chancellor of 11 State Universities and Visitor of 6 private Universities. He was conferred with the Degree of Doctor of Science (D.Sc) Honoris Causa by the University of Engineering and Management, Kolkata in September 2017 and was awarded the Honorary Doctorate of Letters and named as an Honorary Fellow of the Swansea University, UK in 2018. He was given the Honorary Fellowship of The Institution of Engineers (India) in December 2011. The Paul Appleby Award for 2016 was conferred upon him. He served on the Board of Governors of DeSales University, USA. Shekhar Dutt has authored 2 books and a number of articles on national security, development and solar power in various journals and compilations.

At present, he is Member, Executive Council of the Indian Institute of Public Administration (IIPA), New Delhi and also associated with Centre for Joint Warfare (CENJOWS), Ministry of Defence, GOI; Solar Power Developers Association, Indian Association for the Study of Traditional Asian Medicine (IASTAM) and Global Counter Terrorism Council (GCTC) in various capacities.

Engineering for the Future

Shri Shekhar Dutt
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Human evolution of recent times has been impacted by some major breakthroughs that can easily be termed as revolutionary. The Agricultural Revolution brought about the concept to Territory and stability in terms of settlement. The Industrial Revolution, similarly, brought about the concept of mass production and defined the value of materials and resource including energy. We, today, are a part of another revolution that is generally referred to as the knowledge revolution. The synergy between Technology and Human intellect defines this revolution. The rate of change of this relationship and its impact on our lives is 'phenomenal'. I cannot find a more appropriate adjective to describe what we are experiencing. The Young Engineers are a substantive part of this revolution.

The basic change in fundamentals that this revolution has caused is in the understanding of the word 'Space'. Mathematical representation of volume, length breadth, height and even distance can no more define space completely. The capacity of space is now defined by time and how much information it can carry between multitude of originators and recipients simultaneously. Even 'communication' is no more about 'conversation' alone. It involves being specific and precise. The mathematical representation about the position of points in communication at a particular point and the accuracy of information is all about Data and Meta Data. Cyber Space means all this and much more. There is thus an element of nationality about space in today's world. In certain situations the impact of this change is quite radical. Everyone therefore confront a major challenge.

To this myriad of inter twined factors we need to include artificial intelligence. Since the human mind cannot be burdened with fixed responses, much of today's machines and network employ artificial intelligence in some or other from. Our energy transmission and load share change does this as a part of our daily life. Everyone is now aware of the vulnerabilities in this area and how hostile action by the competitors and adversaries could paralyse their operations. In modern competitive world, protecting a network and keeping it in constant operation is a mandatory requirement. The vulnerabilities lie across the board and include the originator, the medium used and the recipient. In a fast paced environment in which data exchange is taking place nearly instantaneously, the need to be doubly sure becomes critical.

The Future of Work in the field of Development of New Technologies has been a topic of conversation among policy makers and other stakeholders in industrialized economies for the past decade. The notion of 'creative destruction' articulated by Schumpeter is often used in the discourse on the impact of technological change, and emerging technologies, on employment. In other words, this happens when destruction of some jobs is compensated by the creation of new employment opportunities. Innovations like Robotics, Artificial Intelligence (AI), Virtual/ Augmented Reality, Internet of Things (IoT), Cloud and Quantum Computing, 3D Printing, Electric and Autonomous vehicles, Renewable Energy sources, Machine Learning, Big Data operation, Medical Sensors, Nano Technology to name a few, will increasingly transform the global economy and displace many in the human workforce and at the same time create many more jobs. Some key findings by researchers indicate that Artificial Intelligence (AI) will automate millions of people out of work but is likely to create many million jobs too. While some jobs will be lost due to AI, a number of positions will develop around AI like AI trainees, individuals to support data science and capabilities related to modelling, machine learning and neuroscience.

Cloud-Based Computing and Communication Platforms will become more widespread and enable organizations to leverage the benefits of a remote workforce effectively. The experience of the world and also that of India during the ensuing Covid period has shown that considerable work can be done from remote locations without affecting the efficiency and efficacy. There will be significant job openings in this area of expertise also. Quantum computing will find increasing usage, and generate requirement of professionals trained in it.

With greater integration of data flows regionally and around the world, increasing usage of AI, Internet of Things (IoT) and other new technologies, the demand for cyber security experts is soaring while supply is critically low. Cyber Security is important now but will gain even greater importance in the years to come.

Augmented and Virtual Reality (AR and VR) are demonstrated to be playing an increasingly significant role in industries such as healthcare, construction, designing's of new technology in equipments of oil, gas and aerospace. Block chain was being increasingly used for transactions and information exchange that also requires a high level of security.

In India, it is not only the IT companies which are in urgent need of trained and expert professionals in emerging technologies. According to press reports, old economy companies are also stepping up hiring of technology professionals as the demand for tech savvy and digitally talented workforce grows. Manufacturing, retail, banking, and financial services companies are developing cutting edge technologies which require such talent.

The coming years will see a sharp increase in demand for professionals with skills in emerging technologies such as Artificial Intelligence (AI) and machine learning, even as people with capabilities in Big Data and Analytics will continue to be the most sought after by companies across sectors, say sources in the recruitment industry. The Indian IT industry, with a strong focus on Digital India, would require 50 per cent more workforce. AI alone will create millions of jobs globally.

The domestic IT job market is in a revival mode. Job seekers and techies with right skills will be in a 'great' position to capitalize on this trend. One in five companies will use AI to make decisions in this decade. It will help companies offer customized solutions and instructions to employees in real-time.

Old generation text analytics platforms were complex. Few companies were successful in analyzing text data. With deep learning in AI, it will be possible to successfully analyze both structured and unstructured text data.

NANOTECHNOLOGY RELATED DEVELOPMENTS

Nanotechnology is sometimes referred to as a general-purpose technology. That is because in its advanced form it will have significant impact on almost all industries and all areas of society. It will offer better built, longer lasting, cleaner, safer, and smarter products for the home, for communications, for medicine and medical electronics, for transportation, for agriculture, and for industry in general.

Imagine a medical device that travels through the human body to seek out and destroy small clusters of cancerous cells before they can spread, or a box no larger than a sugar cube that contains the entire contents of the National Library. Or materials much lighter than steel that possess ten times as much strength. That is the capability of nanotechnology of today.

Like electricity or computers before it, nanotechnology will offer greatly improved efficiency in almost every facet of life. But as a general-purpose technology, it will be dual-use, meaning it will have many commercial uses and it also will have many military uses as well — making far more powerful weapons and tools of surveillance. Thus, it represents not only wonderful benefits for humanity, but also engineer extremely effective delivery mechanism.

A key understanding of nanotechnology is that it offers not just better products, but a vastly improved manufacturing process. A computer can make copies of data files—essentially as many copies as you want at little or no cost. It may be only a matter of time until the building of products becomes as cheap as the copying of files. That's the real meaning of nanotechnology, and why it is sometimes seen as "the next industrial revolution".

Nanotechnology not only will allow making many high-quality products at very low cost, but it will also allow making new Nanofactories at the same low cost and at the same rapid speed. This unique (outside of biology) ability to reproduce its own means of production is why nanotech is said to be an exponential technology. It represents a manufacturing system that will be able to make more manufacturing systems—factories that can build factories—rapidly, cheaply, and cleanly. The means of production will be able to reproduce exponentially, so in just a few weeks a few nanofactories conceivably could become billions. It is a revolutionary, transformative, powerful, and potentially very dangerous or beneficial technology.

Nanotechnology involves manipulating properties and structures at the nanoscale, often involving dimensions that are just tiny fractions of the width of a human hair. Nanotechnology is already being used in products in its passive form, such as cosmetics and sunscreens, and it is expected that in the coming decades, new phases of products, such as better batteries and improved electronics equipment, will be developed which will be having far-reaching implications.

One area of nanotechnology application that holds the promise of providing great benefits for society in the future is in the realm of medicine. Nanotechnology is already being used as the basis for new, more effective drug delivery systems and is in early stage development as scaffolding in nerve regeneration research. Moreover, the National Cancer Institute has created the Alliance for Nanotechnology in Cancer in the hope that investments in this branch of nanomedicine could lead to breakthroughs in terms of detecting, diagnosing, and treating various forms of cancer.

Nanotechnology medical developments over the coming years will have a wide variety of usages and could potentially save a great number of lives. Nanotechnology is already moving from being used in passive structures to active structures, through more targeted drug therapies or "smart drugs." These new drug therapies have already been shown to cause fewer side effects and can be more effective than traditional therapies. In the future, nanotechnology will also aid in the formation of molecular systems that may be strikingly similar to living systems. These molecular structures could be the basis for the regeneration or replacement of body parts that are currently lost to infection, accident, or disease. These predictions for the future have great significance not only in encouraging nanotechnology research and development but also in determining a means of oversight.

Nanotechnology as we see is a group of emerging technologies in which the structure of matter is controlled at the nanometer scale, the scale of small numbers of atoms, to produce novel materials and devices that have useful and unique properties. Some of these technologies impose only limited control of structure at the nanometer scale, but they are already in use, producing useful products. They are also being further developed to produce even more sophisticated products in which the structure of matter is more precisely controlled.

We are living in a time of extreme and rapid change: every industry is being disrupted by AI or automation, new technology that increases efficiencies but drastically changes the workplace landscape. Some experts predict that by 2050 there won't be single human working on a construction site or factory.

Over the next three decades we'll see more development and changes in the field of engineering than possibly ever before. Some elements of machinery will be autonomous and self-assembling, more of our data will be collected, and our cities, workplaces and homes will be radically changed. The population is expected to reach 9 billion by 2050, with two thirds living in cities and urban areas.

SOME CHANGES IN ENGINEERING OVER THE NEXT THREE DECADES:

a) Engineering will become safer

With every large-scale technological upgrade in the engineering industry comes a rise in safety levels. As we move into a new age of unprecedented technological power and control, we may, too, be moving towards a working world of zero harm; engineers who may once have been working in dangerous fields would find themselves in safer working conditions thanks to AI overseers, automated safety protocols and stronger defensive measures than ever before.

b) Wearable Technology Will Become Commonplace

Leading on from the previous point about safety, part of this will be due to wearable technology. Wearable technology may take many forms, but in the field of engineering many are proposing wearing reinforced garments to increase strength, maneuverability, reflexes, safety and productivity. These wearable suits, which previously were only seen in science fiction, may soon make workplace accidents a thing of the past.

c) Concrete and Steel will be replaced with Smart Materials

Smart materials have been around for decades but haven't yet superseded traditional building materials. As we move into a more futuristic world, buildings may be constructed of entirely different materials to allow them respond to stimuli instead of being passive structures. Self-healing materials can react to damage or long-term wear and tear by repairing themselves over time. Other materials can turn walls into solar panels so our cities generate the very energy they run on. Any materials that can lessen or even absorb carbon emissions will be in high demand as the world becomes more focused on reducing pollution. Making such smart material will also in all likelihood, engage a large work force distributed all over and specially at the construction centres. Using such materials transformation of present cities to smart cities will be possible.

d) New Jobs Will Be Created

Some jobs will be entirely automated by 2050. However, new jobs will emerge in unexpected ways into unexpected fields that don't exist today. By all forecasts, half of children in school today will work in jobs that currently do not exist.

Engineering must become more agile, with flexible workers with a variety of soft and interpersonal skills, as well as a focus on creativity, design, and analysis. These are skills and qualities that machines cannot replicate and will help the engineering workforce to continue to drive progress forward using their ingenuity.

e) Containing Cyber-Crime will become an important vocation

As the Internet of Things (IoT) becomes more connected and widespread, almost everything in our homes and workplaces will be connected to the internet. Smart appliances could leave us vulnerable on a societal and personal level to cyber-crime. Protection will be required to be implemented at every level, starting with the Government and moving down from business to individual. Critical infrastructure must be protected as a priority to prevent cyber-attacks on our financial service, health service, police or military. Best practice must be established and followed to ensure everyone is as safe as possible. Designing electronic hardware, capable of detection and preventing cyber crime, will be constantly required engaging a band of intelligent and ingenious engineers.

f) Infrastructure

As the world changes, the infrastructure that supports the world will have to change as well. Our towns and cities will change to support new modes of transport, new energy generating and distribution systems, new ways of living and working, and will likely be almost unrecognizable to us now. The infrastructure we are beginning to see today must be future-proofed for the technology of tomorrow, able to adapt or be redesigned to integrate with an ever-changing technological landscape.

With the significant advances in science and technology, computing and engineering scholars shall continue to play a significant role over the next few decades. With increased usage of mobile computing and cloud technology increasing numbers shall be learning to operate digitally and develop new apparatus and systems capable of handling a large number of operations at the same time. The personnel who can skillfully handle and develop such systems shall continue to be in high demand.

With increasing populations and surge in urbanization the need for smart infrastructure will grow. Construction and maintenance of new roadways, water supply arrangements, power generation and distribution networks, clever waste management and recycling systems and development of smart townships would become a necessity.

Water would be a crucial and scarce resource and shall require to be conserved. Therefore, used water would require recycling and aquifers would require to be recharged. Management of water resources would thus become crucial to our well being.

A much greater usage of Renewable Energy (RE) will be required all over the Globe, and therefore, continuous development for increasing efficiency and efficacy of solar and wind energy would be the order of the times.

Since the advent of mankind, the search for methods of attaining immortality has always been at the uppermost in the mind of the human civilization. Genetic engineering with the help of nanotechnology ably supported by micro electronics and embedded technology will open up an entirely new direction of medical treatment engaging increasing numbers of the brightest young applied scientists. At the same time the quest for finding ‘new molecules’ will lead the intrepid of the pharmaceutical world to evolve new medicines and new line of treatment having less or no side effects or after effects.

Biomedical-engineering is yet another field which will draw the interest of the brightest of the bright. I know of one such person of my generation. His name is Prof Dr Sujoy Kumar Guha. He studied electrical engineering at IIT Kharagpur, then went on to do higher studies in USA. After completing his Ph.D there he taught in a University and also worked in the field of developing medical electronics products. He then thought of having a greater knowledge of medical science and came back to India to study medical science. After which he worked in two hospitals in India. He is considered to be a pioneer in the field of Biomedical Engineering in India. He has been instrumental in designing a number of biomedical products. The Government of India has honoured him with the Award of Padma Shri.

At this point we may also like to remember the engineer stalwarts who have put India into the unique position of being a handful amongst the countries of the world in certain strategic and highly technical fields. Dr. Homi J. Bhaba was one such person. An Engineer by discipline, he took India to be one of the very few countries of the world which acquired the position of having its own Atomic Energy plants and also designed the Bhaba Atomic Research Centre. Similarly, Dr. Vikram Sarabhai and Dr. Satish Dhawan set up the Indian Space Research Centre (ISRO) to put India along with a handful of countries having the capability of launching and placing satellites in space. Dr. A.P.J. Abdul Kalam was yet another engineer who crafted the missile capability of India.

At the time when these pioneers started their work, India had very few resources to put into this task, very little money. So these remarkable engineers worked against all the odds and displayed not only outstanding engineering capabilities but also demonstrated tremendous leadership abilities to create the capabilities as well as the concerned organizations. Many more such pioneers of Engineering are required in India now, in the twenty first century. It will be, only then, that India would find its legitimate place amongst the leading countries of the world.

Shri Durga Shanker Mishra
Secretary, Ministry of Housing and Urban Affairs, GoI, Nirman Bhawan, New Delhi

Author's Profile

Shri Durga Shanker Mishra is currently the Secretary of Ministry of Housing and Urban Affairs. He is a 1984 batch Indian Administrative Service (IAS) officer of Uttar Pradesh cadre. Shri. D. S. Mishra is also the Chairman of the Delhi Metro Rail Corporation.

Shri D S Mishra has an undergraduate degree in Electrical Engineering from Indian Institute of Technology (IIT) Kanpur and an MBA from the University of Western Sydney. He also holds a postgraduate diploma in public policy from International Institute of Social Studies, The Hague. In addition, Shri D S Mishra holds a postgraduate diploma in human resource management.

Shri D S Mishra has served in various key positions for both the Government of India and the Government of Uttar Pradesh during his career.

Emerging Engineering for Urban Transport Infrastructure

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INTRODUCTION

Urbanization is one of the most glaring realities of the 21st Century. The 2011 Census had shown that urbanization is gaining momentum in India, where every third person was living in urban areas and it is expected that share of urban population will increase over 50% by 2050. The number of million plus cities presently is 53 and the urban economy accounts for over 60% of the GDP[1]. The economic efficiency of a city depends on the effectiveness of its transport system i.e. efficacy with which people and goods can reach their destinations in the city or its peripheral development areas. The predominant trends influencing mobility in our cities has resulted in a rapid growth of personal motor vehicles, which has manifested itself in severe congestion, increased air pollution, high incidence of road accident deaths and large consumption of imported petroleum fuels.

Realizing the rapidly growing problems of Urban Transport, Government of India approved the National Urban Transport Policy (NUTP) in April 2006. The Policy was one of the first structured initiatives that focussed on moving people and not vehicle and stressed on incorporating Urban Transportation as an important component of urban development at the planning stage, rather than a consequential requirement. The policy set the tone for countering the mobility problems of big cities, recommending that they be addressed through demand management, and investments in public transport systems.

The sustainable development of all urban centres largely depends upon their physical, social and institutional infrastructure. In this context, the importance of transport infrastructure is paramount. Hence, the focus on providing sufficient and quality public transport in cities is as critical as improving the inter-city connectivity. In order to sustain the growth, a High Powered Expert Committee set up by the then Ministry of Urban Development (MoUD) estimated that nearly ₹ 31 lakh cr. was needed to be invested on urban infrastructure during the period 2012-31; out of this 56% was to be allocated to urban roads and 17.7% to mass transit systems[2]. This underscores the importance of urban transport infrastructure in the investments that need to be made in cities.

A glance at the world's developing nations indicates that well planned Mass Rapid Transit Systems (MRTS) sow the seed for a balanced urban transit experience. Burgeoning cities need to adopt a sustainable approach towards urban planning and mobility systems. The country, under its current visionary leadership of Hon'ble Prime Minister Shri Narendra Modi is focusing on several initiatives geared towards energy-efficient and low-carbon transport systems to reduce emissions from this sector; like providing mass transit systems at rapid pace, fuel economy norms, hybrid & electric mobility, improved emission standards, etc.

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2. "Report on Indian Infrastructure and Services", High Powered Expert Committee for estimating the investment requirement for urban infrastructure services, March 2011, http://icrier.org/pdf/FinalReport-hpec.pdf.

INDIAN METRO RAIL NETWORK AND EXPANSE

India (like many other developing countries) has lagged behind; though for its first metro in Kolkata, foundation was laid in 1972 and it started train service in 1984 and got completed in mid 90s. The reasons could be attributed to lack of fund planning as it is known that such projects require huge capital investments, a long gestation period and complex technology for which perhaps railways was not geared up at that time. Thereafter for about ten years, there was no addition in metro network in the country. First modern metro system commenced its operation in the year 2002, when Delhi Metro started service on 8 km stretch between Tees Hazari and Shahadara. Since then, the growth of metro network has seen steady increase, which got accelerated since 2014. Today nearly 700 km network is operational in 18 cities and construction is under progress on over 910 km in 27 cities; this includes construction of 82 km Regional Rapid Transit System (RRTS) between Delhi and Meerut.

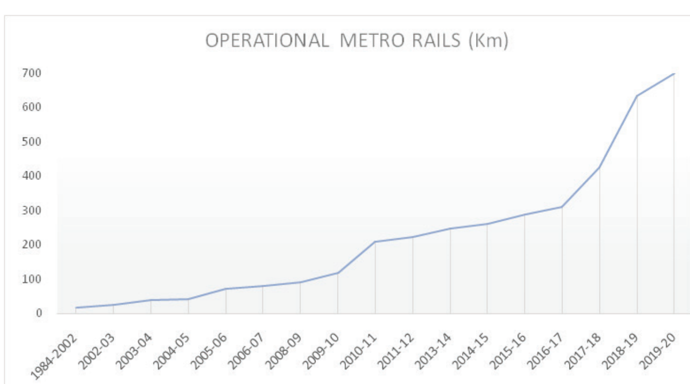
Any new initiative brings along with it a bouquet of challenges and that has been the case for metro rail systems as well. The key among them are huge capital investment, non-standardized technology resulting in higher costs of construction and operations, and inadequate last-mile connectivity. For addressing these challenges, the following initiatives have been taken by Government of India:

a. **Metro Rail Policy, 2017:** Considering the imminent need for enhancing mobility in cities through metro rails, the Union Cabinet, in August 2017 approved the New Metro Rail Policy focusing on compact urban development, cost reduction, last mile connectivity, Public Private Partnership (PPP), Transit Oriented Development (TOD) and multi-modal integration. The Policy seeks to fulfil rising metro rail aspirations of many cities in a responsible manner. It treats the urban mass transit project as "urban transformation projects" rather merely as "urban transportation projects". The Policy emphasises on standardization and indigenization of metro rail components.

> "The Metro Rail Policy is 'reform oriented' by ensuring that the metro trains are linked with feeder buses. New walkways and pathways are being developed simultaneously."
>
> Narendra Modi, Prime Minister of India

b. **Value Capture Financing:** The Value Capture Finance (VCF) Policy Framework, 2017[3] identifies tools such as transferable development rights (TDRs), betterment levy, fee for changing land use, vacant land tax, land pooling system etc. as sources of financing infrastructure projects. The Metro Rail Policy prescribes adoption of VCF and transfer of financial benefits accruing in metro influence zone to the metro company as additional source of financing.

3. http://www.smartcities.gov.in/upload/5901982d9e461VCFPolicyFrameworkFINAL.pdf



c. **Transit Oriented Development (TOD):** Government of India issued National TOD Policy 2017[4] with the objective to integrate land use and transport planning to develop compact and inclusive growth centres within the influence zone of 500 - 800 meters. This will promote public transport usage and achieve reduction in the private vehicle ownerships.

d. **Multimodal Integration:** The National Urban Transport Policy, 2006, recommends multimodal integration as the most critical requirement in creation of seamless public transport services. This has been reinforced in the Metro Policy, 2017.

e. **New Technologies in Indian Metro**

   i. Signalling system: Metro systems have adopted state-of-the-art Communication Based Train Control (CBTC) signalling system. For semi high speed rail transit system European Train Communication System (ETCS) is being adopted. Such signalling system allows monitoring location of train through radio network, instead of track circuits as earlier and thus flexibility of "Moving Block" operation with design to operate trains with as close as 90 second headway. It increases infrastructure utilization substantially while easing out commissioning due to far less requirement of cable laying. High bandwidth communication between train and the Operation Control Centre (OCC) facilitates real time monitoring of health of the train and its operation remotely.

   ii. **Driverless/ Unmanned Train Operation:** This system offers high level of reliability besides flexibility in induction and withdrawal of trains as per operational requirement due to elimination of human intervention. It is being implemented on line 7 and 8 of Delhi Metro.

   iii. **Use of Technology in maintenance:** Metro Companies have introduced technology for condition monitoring and asset management, which has resulted in improved maintenance intervention and reduction of manpower to a considerable extent.

   iv. **Energy Efficiency:** Energy contributes to one third of life cycle cost of a Rolling Stock. Some of the improvement measures initiated by Metro Companies over the years are to recover energy through regenerative braking system, LED lights for headlight and saloon lighting with sensor control, energy efficient air conditioning system, propulsion system, use of Silicon Carbide (SiC) semi-conductor devices, high efficiency traction motor etc.

   v. **Standards for Metrolite and Metro Neo:** Ministry of Housing & Urban Affairs is committed that each class of city and towns, and not just the large ones, get innovative mobility solutions through implementation strategy. In light of this, and the vision of Hon'ble Prime Minister for "Sabka Saath, Sabka Vikaas, Sabka Vishwas", Light Urban Rail Transit Systems named 'Metrolite' and 'Metro Neo' have been developed since 2019. These systems are suitable for tier-2 cities, or peripheral development areas of mega cities, where traffic demands are less. These systems will provide similar experience to the commuters in terms of comfort, convenience, and punctuality as of metro, albeit, at a much lower cost.

   vi. **Regional Rapid Transit System (RRTS):** For ensuring a balanced and sustainable growth through better connectivity and access in the entire region, Regional Rapid Transit System (RRTS) projects have been envisaged across the National Capital Region (NCR), to provide fast connectivity between Delhi and its satellite towns. The environment friendly

4. http://mohua.gov.in/upload/whatsnew/59a4070e85256Transit_Oriented_Developoment_Policy.pdf

and very low emission RRTS network will carry many times more people at high speed (160 kmph operating and 180 kmph designed speed), while occupying just 3 metre space on land thus reducing congestion on the roads. 82.15 km long Delhi-Ghaziabad-Meerut corridor with 16 stations is the first RRTS in the country that will take less than 60 minutes between the two ends with stoppages on all stations.

INDIGENIZATION & MAKE IN INDIA

In order to promote indigenization and reduction in cost, the specifications of various metro rail components like rolling stock, signalling & telecom systems, electrical & electromechanical systems and civil engineering structures have been standardized. Also, directions have been issued to all metro rail corporations that minimum 75% of the tendered quantity of rolling stocks shall be manufactured indigenously; which in turn brought in global manufacturers like Bombardier and Alstom to form their subsidiaries and joint ventures in the country. Accordingly, four Metro coach manufacturing units viz. Bombardier Transportation at Savli near Vadodara, Alstom Transport India at Sricity near Chennai (Tamil Nadu), Bharat Earth Movers Limited (BEML) in Bengaluru and Titagarh Firema Spa in Kolkata have been setup in the country. As per International Association of Public Transport (UITP)[5], the capital cost of a coach manufactured in India is around ₹ 89.4 million (US$ 1.35 million), which is far lower than the cost in Vancouver (US$ 2.5 million) and San Francisco (US$ 2.30 million)[6].

DMRC has developed indigenous Automatic Train Supervision System (iATS) in collaboration with Bharat Electronics Ltd. (BEL). This is an important sub-system of signaling system, which manages train operations by weaving core signaling functions of train protection and safety aspect with interface to the other systems such as Traction, Rolling Stock, Public Information System etc. and provides several value added services for an efficient operation and superior travel experience. This Make in India system will become operational on one line of DMRC by June 2021 and subsequently be rolled out on other lines & metro rails in other cities.

FUTURISTIC SMART TRANSPORTATION

Smart transportation systems have created demand for solutions like modern Communication Systems, Smart Card Ticketing, Global Positioning System (GPS), Intelligent Transport System (ITS), access control systems, CCTV cameras, station and in-vehicle safety & lighting systems, elevators & escalators, passenger information system and programming & scheduling system. Some of the other important initiatives taken by Government of India are as follows:

- **National Common Mobility Card (NCMC):** National Common Mobility Card (NCMC), is an inter-operable transport card conceived by the Ministry, which enables the user to pay for travel, toll duties (toll tax), retail shopping, and withdraw money, enabled through the home-grown RuPay Card ecosystem and is a Make in India project. Brihanmumbai Electricity Supply and Transport (BEST) buses are set to become the first public bus transportation in India to roll out the National Common Mobility Card (NCMC)[7]. Most of Metro Rails have adopted this as their payment system for new developments and are retrofitting in old ones.
- **Automatic Fare Collection (AFC) System:** On the initiative of Ministry, CDAC in collaboration with NPCI, BEL, DMRC and SBI has developed AFC Gate and payment ecosystem which has been internationally accredited and is being used in Metro Rails and Urban Bus Systems. This is an important contribution under Make in India and has scope to be exported to other countries once it gets fully stabilised in our systems.

5. A non-profit advocacy organisation for public transport authorities and operators
6. https://www.industrialautomationindia.in/articleitm/6686/Metro-Coaches-%E2%80%93-A-Make-in-India-Success-Story/articles
7. https://en.wikipedia.org/wiki/National_Common_Mobility_Card

- **Intelligent transport systems (ITS):** As cities turn "smart", smart transportation is a crucial element in realising their vision. Intelligent Transportation System (ITS) involves a number of Information and Communication Technology (ICT) interventions used for efficiently managing transportation. Smart City based smart transportation are developed with smart infrastructure that includes not only multi-modal connected conveyance but also automated traffic signals, tolls and fare collection.
- Non-Motorised Transport (NMT): The Ministry of Housing & Urban Affairs asserts that NMTs should occupy the prime, non-negotiable, position in every form of urban mobility discourse and intervention. Initiatives such as Cycles4Change Challenge and Streets4People Challenge of the Smart Cities Mission will inspire and support Indian cities to quickly implement cycling-friendly and pedestrian-friendly initiatives in response to the current COVID-19 crisis. The Challenges aim to help cities connect with their citizens as well as experts to develop a unified vision and initiatives to promote cycling & pedestrianization.

WAY FORWARD

Given the far-reaching effects that transportation has on energy consumption and carbon emissions, the country needs to adopt sustainable transport modes and improve performance in all modes by adopting new technologies. From the established transit modes such as metro rails, city buses, Bus Rapid Transit System (BRTS) etc., there may indeed be opportunities in which self-reliance should be supported and expanded for people to move around in our cities. This may include shared modes of transport like Ola, Uber etc. or other innovative approaches where mobility is provided as 'service'. Hon'ble Prime Minister Shri Narendra Modi, in his address to the nation emphasized that time is ripe for 'Atma-Nirbharta' (self-reliance) and it is "time to be vocal about local". Transition to more sustainable transport systems needs to happen now, before infrastructure investment locks in automobile dependence. In order to avoid catastrophic climate change, cities worldwide and in India must pursue a different and more sustainable path of transportation development.

> India proceeds towards the goal of becoming a 5 trillion dollar economy, our cities too should become cities of the 21st century. In line with this goal, the Government is spending ₹ 100 lakh crore in next five years on building modern infrastructure.
>
> Narendra Modi, Prime Minister of India

In future development, our focus is on bringing down the cost, improving comfort & convenience to commuters, and increasing indigenisation. Recently, we have increased the local content in various components of the Metro Systems. The minimum levels to be adopted by Metro rail companies for different components are now Civil Engineering Works-90% (elevated) & 80% (underground), Rolling Stocks-60%, Electrical & Mechnaical-60%, Telecom- 50% and Siganling-50%[8]. We should ultimately take these numbers to 100% in few years and become net exporter of all these items i.e. local to global. For this, the key is innovation and use of upfront technologies available across the globe to bring down cost, improve efficiency and encourage globally competitive products.

Strengthening the public transport with last mile connectivity, promote NMT and enabling ICT (Information and Communication Technology) for transport will minimise the rate of vehicular growth, notwithstanding the increase in service demand. It is thus imperative to conclude, that a combination of many such strategies need to be implemented in parallel to create a resurgence in urban transport sector, which would definitely have a long term positive impact on job creation and sustainable development. This approach will provide key to the transport engineering for Aatma Nirbhar Urban India.

8. http://mohua.gov.in/whatsnew.php

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Author's Profile

Ashutosh Sharma is a Secretary to the Government of India since January 2015, heading the Department of Science and Technology (DST), where he helped initiate several new programs and facilitated major international collaborations in the areas of priority for the nation. Ashutosh Sharma received his PhD from the State University of New York at Buffalo (SUNYAB; 1988), his MS from the Pennsylvania State University (1984) and B.Tech. from IIT Kanpur (1982). He has been a professor (1997-), an Institute Chair Professor (2007-) and the Head (2003-05) of Chemical Engineering, and the founding Coordinator of Nanosciences Center and Advanced Imaging Center at the Indian Institute of Technology at Kanpur.

His research contributions are highly interdisciplinary and he has published over 350 peer reviewed papers, filed over 15 patents, given over 150 invited or key note conference presentations and mentored a successful nanotechnology startup. Ashutosh is a recipient of numerous honors and awards including the inaugural Infosys Prize, TWAS Science Prize, Bessel Research Award of the Humboldt Foundation, J. C. Bose Fellowship, S. S. Bhatnagar Prize, Homi J. Bhabha Award of UGC, The Syed Husain Zaheer Medal and the Meghnad Saha Medal of INSA, Distinguished Alumni Awards of IIT Kanpur and SUNY Buffalo, Firodia Award, the Life-time Achievement Award of the Indian Science Congress and several Doctor of Science honoris causa, including from SUNY Buffalo, and Jadavpur University.

Ashutosh is an elected Fellow of The Indian National Science Academy, The Indian Academy of Sciences, The National Academy of Sciences, India and Indian National Academy of Engineering, The World Academy of Sciences (TWAS) and the Asia-Pacific Academy of Materials. He has also served on the Councils of the first two. He has been an associate editor of ACS Applied Materials and Interfaces, Proceedings of Indian National Science Academy and also associated with many other international journals of repute.

Ashutosh's other interests are in ancient history and philosophy, poetry and art.

Engineering for Atmanirbhar Bharat

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INTRODUCTION

Science and Technology (S&T) policy drives the economic progress and holistic development of any nation. Development has different connotations but for a healthy nation, development should be people-centric rather than only driven for wealth generation and economic growth. India is an emerging economy wherein S&T is accorded the highest priority as it leads to economic growth, provides employment and ensures socio-cultural progress. A strong connect between science, technology and innovation with societal outcomes, will fuel sustainable economic and social progress for India.

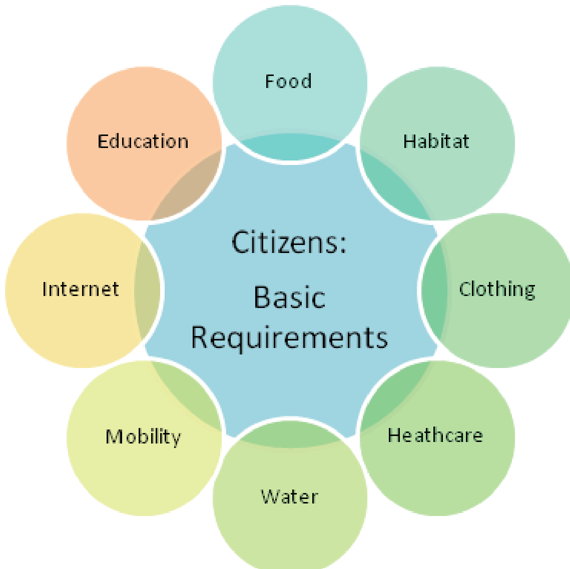
Shri Narendra Modi, the Hon'ble Prime Minister of India, in his address at the 107th session of the Indian Science Congress in January 2020 has given thrust on innovation and said "innovation for the people and by the people is the direction of our New India". On these lines, the Government of India is in the process of finalizing 'Scientific Social Responsibility Policy' similar to corporate social responsibility, in order to strengthen communication between S& T institutions, individual scientists and society to build a strong science-society connect.

India's development path is being designed on three key coordinates i.e. Atma Nirbhar (attaining self-reliance), achieving Sustainable Development Goals and fulfilling commitment to Climate Change abatement. Therefore, we need to strike the right balance between economic growth and environmental sustainability and has to tread tactfully in the path of development with a strong Science, Technology and Innovation framework.

Inspite of several impediments, there are many opportunities which can be harnessed to strengthen our country's capability and become a global leader. The country's strength lies in its young talent pool, traditional knowledge-based products and frugal innovations. Concepts of lean, clean and green with zero waste have to be imbibed in processes so as to ensure resource optimization and minimum impact on the natural resources and environment.

INDIAN SOCIETY

Basic requirements are generally defined as minimum needs for human beings to lead a decent quality life. The traditional phrase of Roti-Kapda-Makaan as basic requirements is not in vogue now. The re-defined modern definition of basic requirements denote Education, Healthcare, Water, Energy and Internet connectivity as depicted below.



The Technology Vision 2035 document of TIFAC has set a vision "Technology in the service of India: ensuring the security, enhancing the prosperity and strengthening the identity of every Indian", which clearly emphasizes that technology is the fundamental element leading to overall societal upliftment. Therefore, accessing, developing and leveraging technology would remain the core area of National interest. Technology not only empowers its citizens but also empowers the entire country. It is pertinent that, as citizens, we need to gain confidence in our own technological capabilities.

India's economy, during the past few years has been more or less steady **(Table 1)**. A quick study of the global economy shows that following USA, China has the second-largest share of global GDP, with India racing with Japan for third-largest position. It needs to be noted that India still managed to record impressive GDP growth rates inspite of the recession which prevailed worldwide in 2008-09, wherein many countries witnessed a backward trend in GDP during that phase, at least at some point of time.

Post COVID-19 pandemic, the world is witnessing a major transformational change with altered global order and disrupted supply chains. The current situation seems to pose a short term crisis, however, there is a silver lining in the longer term. This has created an unique opportunity for India to position itself as a manufacturing hub with a big push under 'Make in India' initiative.

Purchasing Managers Index (PMI), an indicator of economic health of manufacturing sector, of

Table 1: GDP growth rate YOY

Year	GDP growth rate % compared to previous year
2013	6.39
2014	7.41
2015	8.00
2016	8.26
2017	7.04
2018	6.12
2019	4.23

Source: www. statista.com accessed on 29.10.2020

Table 2 : PMI data comparison of countries

Country	Current Sep 2020 (unit-points)	Previous Aug 2020 (unit-points)
Australia	46.7	49.3
Brazil	64.9	64.7
Canada	56	55.1
China	53	53.1
France	51	51.2
Germany	58	56.4
India	56.8	52
Israel	53.5	53.1
Italy	53.2	53.1
Japan	48	47.7
Russia	48.9	51.1
Spain	50.8	49.9
South Korea	49.8	48.5
United Kingdom	53.3	54.1
United States	53.3	53.2

Source: www. tradingeconomics.com accessed on 29.10.2020 a few countries in the last two months, indicates that economic recovery of India is also quicker and at par with other developed nations.

According to the World Bank, the recent export, import data of India shows that the quantum of total exports are to the tune of 322,291,568.43 in thousands of US$ and total imports are 617,945,603.08 in thousands of US$ and has lead to a negative trade balance of -295,654,034.65 in thousands of US$. The trade growth is 0.87% compared to a world growth of 3.50%. GDP of India is 2,718,732,231,300 in current US$. India's services export is 204,955,578,850 current US$ in BoP (Balance of Payments), and services import is 124,181,614,510 current US$ in BoP, India's goods and services exports amount to 19.745 as percentage of GDP and imports of goods and services is 23.64% as percentage of GDP.

(Source: https://wits.worldbank.org/Country Profile/en/IND accessed on 29.10.2020)

This current situation calls for a concerted approach and highlights the critical need for striving towards achieving self reliance in key sectors of economy, especially manufacturing. Need of the hour is to adapt to suitable technologies which could have been developed elsewhere and could meet our needs so that it avoids reinventing the wheel. The next step would be to analyse and through re-engineering, understand from the innovations and further take up the development of environmentally friendly technologies on a fast-track mode. For building up a Self reliant Nation-AtmaNirbharta, we need to develop those key technologies which are critical for our Nation's growth and attain technology independence. In order to confront and tackle technology denial, in case of any, in the future, India will have to rise up and evolve as a key player in the technology production game and successfully encash and leverage its market attractiveness.

An analytical evaluation into each sector charting out their current status/demand-supply scenario along with technology interventions/suggestions required is presented in the subsequent section.

DEMAND SUPPLY SCENARIO ANALYSIS/ TECHNOLOGY GAPS OF SECTORS

Agriculture and food processing

In India, Agriculture and allied sectors are the largest source of livelihood and around 56 % of its rural households still depend primarily on agriculture. Growth of agriculture sector is not steady. In 2014, the growth was -0.2% which increased to 6.3% in 2016-17, and then again declined to 2.8% in 2019-20. The Gross Value Addition of agriculture has decreased from 18.2% in 2014-15 to 16.5% in 2019-20. This was mainly because of reduction in share of GVA of crops.

In the last FY (2019-20), food grain production has touched all time high of about 292 million tons (Mt). Production of all crops has established a new record with quantum of rice - 113 Mt (paddy 170 Mt), wheat-100 Mt, nutri/course cereals 47-Mt, maize-29 Mt and pulses - 25 Mt. The country also harvested a record production of horticultural crops, livestock, fisheries and aquaculture. In spite of increased food grain production, the prevailing COVID-19 situation brings out many associated challenges as well as opportunities. This coerces focused attention towards deployment of new and innovative technologies for efficient management of produce and meet up the demands. Concerted efforts in this direction from all stakeholders assume prominence also in the impending scenario of climate change. In this scenario, the target of doubling of farmers' income by 2022 seems to be a herculean task unless innovative and advanced technologies are adopted along with enabling policies.

It is pertinent to say that since the green revolution in 1960s, growth of agriculture sector is quite significant. However, to feed the growing population and demand of agri-based raw material from industry, agriculture productivity has to be increased across all the subsectors using new technologies, including ICT, biotechnology and nanotechnology.

There is an urgent need to fill the technology gap to match productivity ratios with the rest of the world. Keeping in view, the small landholdings flowing out of our social structure, technologies that are globally available for improving farm productivity need to be modified and adapted to suit our needs. Value addition by ingenious processing technologies has the potential of extending utilization of perishable food items. Further, integrated handling and preferential transport of these items, assisted by smart packaging, can help retain their nutritional value and reduce wastage. A few technologies/concepts that will facilitate in ensuring Atma Nirbharta and food security in India are:

- Use of drones for biotic and abiotic stress monitoring and site-specific control measures
- Solar powered farm machine for agri-operations
- Use of Nano-technology: Nano-fertilizer, herbicides, pesticides
- Multi-stress (biotic and abiotic) resistant crop varieties
- Weather-based pest, disease and yield forecasting with simulation modeling
- Use of biosensors for animal nutrition and feed management
- Microbial tools for methane mitigation from ruminants and rice fields
- Zero budget natural farming
- Remote sensing satellite-based soil, water and nutrient management
- Big-data analytics for weather forecasting, water, pest and nutrient management
- Bio-sensor for pest, nutrient and stress management
- Apomixis for fixing hybrid vigour
- Automated tractor for optimal field operations
- Somatic cell nuclear transfer (cloning) for better adaptation and productivity of animal
- Enhancing photosynthetic efficiency (C3 to C4 plants)
- Hybrid seed production using the Barnase/ Barstar system
- Use of saline and waste-water in agriculture

Energy

In India, the Per-capita Energy Consumption (PEC) has increased to 24,453 MJ in 2018-19. At present, the energy needs are met through coal, with thermal power plants contributing to approx. 68% of the total installed capacity in the country with an installed capacity of 282350 MW.

At the end of March 2019, renewable sources (excluding hydro) accounted for 19.2%, Hydro accounted for 10.97%, Nuclear energy accounted for 1.64% and Non-utilities accounted for 14% of the total installed electricity generation capacity (Energy Statistics, MoSPI, 2020).

India has voluntarily pledged that the share of non-fossil fuel will be increased to 40%, by 2022. Towards this, the government has set a target of installing 175 GW of renewable energy capacity out of which 100GW from solar, 60 GW from wind, 10 GW from biomass and 5 GW from hydropower projects.

With these statistics and targets at the backdrop, let us look at the technology gaps:

Coal & Energy Sector

Technology gaps

- With more than 60% energy needs being met by coal, the ash content of Indian coals is high (40 to 50% by weight) resulting in low heating value (about15 to 18 MJ/kg)
- The Advanced Coal Technologies developed for low ash coals are not directly adaptable to Indian high ash coal. Due to this, we are dependent on imported coal. Imports of coal during 2009-10 to 2018-19 increased at a CAGR of 12.37% whereas the export of coal during the corresponding period decreased at (-) 6.06%. Therefore, the challenge is to reduce dependency on imported coal through indigenous technology development for high ash coal, to attain energy security.

- The majority of coal-fired power plants in India are based on sub-critical boiler technology, and usually operate at efficiency levels of below 35%.
- Higher per kWh CO_2 emission (about 791 g) in coal-power generation compared to a global average of about 522 g) (5th IEF-IGU Ministerial Gas Forum, 2016).
- Economically viable coal beneficiation technologies for reduction of ash and sulphur content
- Non-existence of commercially demonstrated and economically viable CO_2 separation, capture, utilization and storage technologies.
- Coal to fluid fuel technologies to support the automobile industry.

Technology Needs

A few technologies which are required to move towards self-reliance in this domain in India are:

- Ultra Supercritical (USC) /Advanced Ultra Supercritical (AUSC)technology for coal plants for overall efficiencies
- Underground Coal Gasification Technology (UCG)
- Coal to methanol, DME and other fluid fuels technology
- Denox Systems for coal power plants
- Advanced Coal Beneficiation technologies
- Carbon Capture, transport and storage technologies
- Gas Hydrates Exploration and Production

Renewable Sector

At present, the installed RE capacity is 84.39 GW which includes 37.28 GW from wind energy, 32.52 GW from solar, 9.94 GW from bio-power and 4.65 GW from small hydro plants whereas the target for 2022 is 175 GW installed capacity. Further, India's Nationally Determined Contributions mention a commitment to achieve about 40% cumulative electric power installed capacity from non-fossil fuel-based energy resources by 2030. Several technology gaps exist in addition to inadequate manufacturing capability of hardware components in this sector.

Technology gaps

- Initial high cost of installation is the biggest challenge for large scale deployment.
- Lack of technology and manufacturing facilities for solar grade poly silicon, ingots and wafers. At present, India is predominantly relying on imports due to cost benefit
- Existing module manufacturing plants lack economies of scale which prevents cost reduction
- High cost of offshore wind power installations, as well as no domestic manufacturing capability
- Need for proper assessment of storage requirement to achieve the projected target
- Decentralized and hybrid grid connectivity for better access to different form of RE power.
- Biomass supply-chain, uncertainty in availability of biomass throughout the year and transportation of biomass.

Technology Needs

The technologies which India needs to focus upon and develop indigenous manufacturing capability striving towards AtmaNirbhar Bharat are:

A) Solar PV:

- Currently, crystalline Silicon (c-Si) technology contributes 95% of global solar PV installations and thin films contribute to the balance. Thus, c-Si is likely to contribute 400 GW by 2050 and is important for India's future clean energy trajectory. India lacks technology and manufacturing for the upstream segment of this supply chain, i.e. poly silicon/ingot/wafer. (CSTEP, 2018a).
- India lacks the crucial technologies needed to process/manufacture the raw materials for cell and module manufacturing.
- Equipment (assembly line) used for cell,

module and BoM component manufacturing is not available in India and are imported.

B) Silicon: Mono Ingots - Cz Process (p and n-types), Multi Ingots - High Performance (DSS Process) and Wafer Slicing Technology, PV technologybased on n-type silicon wafers. Other emerging technologies: CIGS, Back-conduct-Back Junction (BCBJ) modules.

C) CSPs: Upstream technologies are not available.

D) Wind energy: Upstream technologies are not available. There is requirement of indigenous manufacturing of infrastructure (Blade, Gearbox, Generator, Bearings).

- Technology limitation exists in the survey space (oceanographic and geotechnical)
- Heavily dependent on imports for rare earth metals

E) Biofuels:

On exploring the option of alternate fuels, our country has to strive for tapping the Algal bloom. India has huge water bodies. Meaningful utilisation through Algae cultivation would lead to benefits. We need indigenous technologies for tapping Algal Bioenergy and Ligno Cellulose Waste.

The National Policy on Biofuels mandates a blending of biofuels of approximately 20% into transport fuels. The Ministry of Science and Technology and the Ministry of New and Renewable Energy have placed a special focus on algal biofuel. Department of Biotechnology (DBT) has established four Bioenergy Research Centres in the country that integrate basic and translational science capabilities for biofuel development and scale up and the major focus has been on cellulosic ethanol and algal biofuel. Early results of these centres are encouraging and demo scale technologies for cellulosic ethanol have been established in-country.

In order to ascertain the availability of biomass in an organized manner, outcome of TIFAC study titled 'Spatial Information System on Biomass Potential from crop residues over India using geospatial techniques' has resulted in a spatial map of surplus biomass and bioenergy potential. The data from the spatial information system has been uploaded on the web portal named BHUVAN-JAIVOORJA, which would provide availability of different kinds of biomass at any location. This data along with other infrastructural information from the portal would facilitate installation of biomass/biofuel plants.

Priority areas for interventions:

- Large scale enzyme production and scaling up
- Feedstock sourcing
- Economically feasible commercial production of Bio-methanol
- Biomass-to-liquid, Drop-in fuels and ethanol, Cellulosic bio-ethanol (2G)

F) Hydrogen- priority areas:

- Material constraints exist (e.g. Cobalt, Lithium, Nickel)
- Hydrogen production technologies are available but expensive
- Infrastructure for H_2 storage is still under development.

G) Energy storage-priority areas:

- Lithium Ion batteries (LiB) are the most suitable and cost-effective storage technology available. Raw materials and technology are barriers for large scale manufacturing in India
- Redox flow battery
- Super capacitors for higher energy storage capability

Health

Health is indeed a vital component of the overall socio-economic development of any nation and it is the prime responsibility of the Government to ensure the welfare of its citizens so that they are healthy and productive.

Statistics indicate that Indian population is expected to reach 1.55 billion by 2035 with more than 60% of the population in the younger age bracket. Availability of this large working population in their most creative, innovative and productive phase of life provides enormous opportunity for the growth of the country. Providing affordable healthcare services for the young pool would hence be a critical task as it will impact the country's economy and would be a challenge too.

In addition, education and training in skill development are the drivers to decide on optimum utilization of this young human resource into advantage for the country. Adequate training will also ensure a large pool of young and skilled human resources for healthcare sector. More skilled earning hands would ensure more disposable incomes and better access to healthcare. On the other hand as the geriatric population goes up to about 240 million by 2050, the market for preventive, curative and geriatric care would expand if healthcare is adequately financed.

However, India is currently facing several challenges in healthcare which will continue for the next few decades unless corrective measures are initiated. The country is faced with the triple burden of diseases – pandemic communicable diseases (CDs), new and re-emerging infectious diseases and increasing incidence of non-communicable diseases (NCDs) or lifestyle-related diseases. More than half of all deaths are now attributed to NCDs like cardiovascular diseases, type 2 diabetes, cancer and chronic respiratory diseases. On the other hand, tuberculosis, HIV/AIDS, viral hepatitis, vector borne diseases, water-borne diseases, and zoonotic diseases are still major public health concerns.

In view of this mixed bag of disease burden, healthcare would be a major challenge to tackle and will not be an easy goal to achieve and immediate steps to build up robust medical infrastructure are required. New medical technologies will keep on driving changes in the healthcare sector. India has already shown innovation in providing high-quality, affordable, medicines to the world. In the near future, availability of high-technology diagnostic and therapeutic equipment will revolutionize health care delivery.

The rapidly developing areas of genomics, including molecular diagnostics, pharmacogenomics and targeted therapies, regenerative medicine and information-based medicine will be major drivers of healthcare in the near future.

Likewise, medical tourism is sure to grow. The current estimates show a market size of USD 3 billion with the major contributions from private players.

Currently, statistics indicate that the recent Maternal Mortality Ratio (MMR) in India is 113 per 100,000 live births and Infant Mortality Ration (IMR) is 32 per 1000 births in 2018. It is envisaged that by 2035, MMR to be reduced to less than 15 per 100,000 live births and Under-5 mortality rate should be reduced to less than 6 per 1000 by 2035.

There are several initiatives taken by Ministry of Health and Family Welfare towards ensuring quality healthcare services to Indian citizens. The e-Sanjeevani OPD is Government's flagship telemedicine programme, deployed across 155,000 health and wellness centres across the country under the Ayushman Bharat Scheme of the Government and few more such initiatives have brought relief. But still there is a long way to go.

Some issues/gaps which still needs to be addressed in healthcare services sector are

i. Lack of tools/assistive devices in healthcare support specially for rural healthcare delivery

ii. Facilitation of speedy mobility to nearby super speciality hospitals in case of emergency in rural areas

iii. Non availability of suitable manpower/skilled people, clinicians etc

iv. Lack of awareness amongst people especially in rural areas regarding the need of preventive healthcare

v. Need for building up robust medical

infrastructure and capacity building of health care support staff for meeting pandemic situations

vi. Capability building for assessment/early warning for pandemics and epidemics

vii. Integrated digital infrastructure, to bridge the gaps amongst stakeholders of healthcare ecosystem through efficient digital highways

viii. Remote and non-invasive diagnostics, online health monitoring and delivery using IoT, A.I, Chatbots, Virtual Reality in Telemedicine programmes for benefitting people in remote areas

ix. Networked sensors for remote health monitoring, and actuators for drug delivery

x. Communication networks- Information management to be strengthened for improving the efficiency and effectiveness of the public healthcare system.

As regards the pharmaceutical sector, the global pharmaceutical market is around USD 1.2 trillion with API market of around USD 182.2 billion. The pharmaceutical industry in India is third largest in the world, in terms of volume, behind China and Italy and fourteenth largest in terms of value. The Indian industry has a strong network of 3,000 drug companies and about 10,500 manufacturing units. Indian domestic turnover reached Rs. 1.4 lakh crore (~USD 20 billion) in 2019, with exports to more than 200 countries in the world.

Despite a very strong base, due to low-profit margins and non-lucrative industry, domestic pharmaceutical companies have gradually stopped manufacturing APIs, and started importing APIs, which was a cheaper option with increased profit margins on drugs. With availability of cheaper APIs from China, the pharmaceutical industry relies heavily on imports and has moved on to more profitable formulation part from the APIs. In the financial year 2019, India imported about Rs. 249 billion worth of intermediates and APIs; of which around Rs.169 billion was from China. A total of 600 molecules of APIs and Drug Intermediates are imported to India.

Some of the major issues hindering domestic production of APIs pertain to raw material/starting building blocks, solvents, chemicals used for reaction, scale of manufacturing, over dependence on imports, availability and cost of land, high physical infrastructure, cost, inadequate financial support, Low profit margins and fermentation processes.

Some issues which needs to be immediately taken care to make India achieve Atma Nirbharta in Pharma sector are:

i) Need for Biopharmaceuticals/API Production

ii) Indigenous manufacturing of medical equipments/tools

iii) Diagnostic tools/kits – indigenous manufacturing of basic sensors (O_2,CO_2)

iv) Vaccines development.

Information & Communication technology and Electronics

ICT sector in India contributes about 8% to the GDP. Statistics indicate that India's share in global ICT market would move up by about 5% (marked increase from current 0.2%) with the potential of revenue about Rs 7 Lakh Crore in the next 10 years. With such a potential, ICT sector would play a significant role in uplifting the Nation's economy.

The basic supporting technologies for sustainable and robust ICT infrastructure and its enabling platform are Cyber Security, Internet (High speed broadband connectivity, stability and ubiquitous coverage, may be through 4G, 5G and broadband), Cloud to handle huge data, indigenous simulation model for big data analytics, Artificial Intelligence and allied technologies. Post COVID-19, ICT sector has shown immense potential in bridging the digital divide and ushering digital transformation.

Developed countries have recognized the importance of data driven economy and need for putting in place a comprehensive data policy. Our Hon'ble Prime Minister has also underlined the importance of AI and has emphasized that Artificial Intelligence (AI) can play a crucial role in developing solutions in agriculture, creating next generation urban infrastructure, as well as for making disaster management systems in the country stronger. The potential in India is huge as we have around 700 million internet users and around further 600 million potential users with fibre based internet reaching six lakhs villages over the next 3-5 years. Equal digital access is more crucial especially in a pandemic situation to ensure equitable distribution of social and economic welfare measures.

Some technology interventions which need to taken up for realizing the vision of Atma Nirbharta in ICT technologies are summarized below:

Health care delivery: Telemedicine, E-medical Records, IoT enabled healthcare equipments for testing, diagnostics, therapeutics and clinical monitoring

Agriculture: Developing district Agri Stations by utilizing IoT and drones.

Fin Tech: Promoting digital transactions through UPI/E-wallets/digital and crypto currencies.

E-education: Use of AR/VR, online learning platforms, installation and use of low cost Indian educational cloud.

Low cost bandwidth for broadband connectivity

Detection and delivery: Developing machine learning based affordable Robots & Drones equipped with GPS, cameras, IoT sensors to conduct health and agri diagnostic.

Cyber security: Use artificial intelligence, deep data intelligence, machine learning, blockchain, cryptography and encryption, quantum key distribution, behavior detection for endpoint security.

Solar Photovoltaics: Globally solar cell technology has evolved over the last twenty years from bulk crystalline silicon to a mix of bulk and thin-film silicon and other materials like CdTe and CIGS, with multi-junction cells for high-performance niche applications. India too has witnessed the deployment of solar power plants from both the public and private sector. The country has many commercial players in solar panel manufacturing including a few in wafer manufacturing. A combination of factors like diminishing costs of solar panels, climate change concerns with fossil fuels, burgeoning energy needs, shortfall in grid power and the large insolation, the country receives can make solar energy a winning strategy for India.

Forecast studies for Solar Power indicate that in short-term, material innovations will reduce cost of wafers and panels. This may partly come from incremental advances in solid state technology such as better interface passivation and transparent contacts. R&D being pursued in hetero structured and nanostructured cells, light-trapping structures etc. should translate to unprecedented maximum efficiencies. On the other hand, work on flexible organic/ polymer cells, perovskite cells, and dye/ semiconductor sensitized cells should translate to affordable, ubiquitous light energy harvesting – not only solar, but also ambient, presenting great opportunities for India.

National institutions need to develop commercial electronics manufacturing to serve as a platform for R&D commercialization and leveraging the excellence in Indian Circuit and Systems design expertise for Internet of Things (IoT) era. More consortia based R&D centers need to be formed at a National level with collaboration between academic/fundamental research and manufacturing/industrial applications to serve as global centers for international industrial innovations.

For ICT and solar photovoltaics, some technology directions most relevant for India are i) pervasive, energy-efficient, broadband networks of sensing and interface devices, ii) affordable devices for remote biomedical sensing/actuation iii) autonomous networked nanosystems, possibly bio-mimetic for optimal operation, iv) massive solar and ambient energy harvesting, v) maximally efficient energy conversion (e.g. lighting) and storage (batteries) and vi) specialized (i.e. massively parallel) hardware for 'big data' processing.

Immediate interventions include development of indigenous technology for Printed Circuit Board Assembly (PCBA), display devices etc, routers, switches, optical fibres and peripheral electronic equipment for broad band connectivity, capital equipments like machine vision systems, hardware devices for 5G technologies, MEMs, LEDs and flexible display technologies.

ACCELERATING INNOVATION, ENTREPRENEURSHIP AND STARTUP INCUBATION VALUE CHAIN

It is a fact that breakthrough initiatives are made possible through advancements in Science, but beyond the realm of science and technology, innovations play a crucial role in enhancing performance and ensuring availability, accessibility and affordability of services and improved goods.

India has emerged as one of the fastest-growing innovation ecosystems over the last decade. This year, India entered the list of top 50 innovative countries claiming 48th position in the Global Innovation Index 2020. This climb has been progressive in last five years was possible because of systemic interventions carried out in last five years to remove key bottlenecks in innovation and startup ecosystem and improving the larger business climate in the country. However, as a diversified national with differential challenges to tackle the key drivers of innovation, technology and entrepreneurship are required to revisit, redesign, re-engineer key programs to further boost up the evolving national ecosystem to adapt to changing needs and nation's aspirations.

Following strategic challenges need to be addressed to strengthen the ecosystem and some suggested approaches as a way forward:

Encouraging the co creation of new research domains with active participation of Public and private Sector

While public funded institutions are generating technology leads, their levels of utilization by commercial enterprises have been limited. Efforts and achievements of the government, as well as other ecosystem stakeholders, to promote industry – academia linkages, are definitely celebratory but much is left to be done. Creating frameworks that enable public-private partnership and attract investments from industry into R&D system is still a challenge.

Promoting collaborations through clusters

Based on the lessons learned and the impact generated through existing clusters such as Auto Clusters (Chennai, Pune NCR), Pharma & Biotech cluster (Ahmedabad, Hyderabad, Bangalore), IT cluster (Bangalore, Pune, NCR) Fintech cluster (Mumbai, NCR) etc., developing clusters can be a strategic approach for encouraging new emerging tech domains such as smart city/ sustainable habitat, AI, advanced manufacturing etc. These clusters will not only offer a conducive environment but will also stimulate the entire innovation value chain, steer high rates of growth leading to better socio-economic development of the communities living and working within a specific area or territory.

Improving the flow of Technology

India's large population and demographic transitions make Indians vulnerable to epidemics and pandemics like Covid 19. Thus improving public health infrastructure through innovations in biomedical devices and instrumentations is a clearly identified domain to work and make progress. Focusing on translational research by co-utilizing industrial and academic expertise can fast track the lab to market journey of biomedical innovations.

Nurturing Innovation and Startups through Support Programs

The Department of Science and Technology (DST) has been playing a pioneering role in building a deep-tech entrepreneurship ecosystem in India through its various interventions over the last 3 decades. DST has taken a systematic approach over the last two decades by creating a continuum of initiatives. DST initiated the program in 2000 on Technology Business Incubator (TBI), the first time in the country to nurture start-ups. DST also initiated an idea scouting, mentoring, and support program by partnering with leading industries, Intel, Lockheed Martin, Bennett and Coleman, Texas Instruments, etc. Taking cognizance of challenges as posed by valley of death of innovations, DST carved out a new program, National Initiative for Developing and Harnessing Innovations (NIDHI) as an umbrella program under Start Up India initiative for building an innovation-driven entrepreneurial ecosystem in the country. NIDHI catalyzes the creation of solutions for various problems, enabling its commercialization through funding programs to contribute to socio-economic development of the country. The component of NIDHI-Promoting and Accelerating Young and ASpiring technology entrepreneurs (PRAYAS), specifically targets to support young innovators turn their ideas into PoC. This support allows innovators to execute their ideas without fear of failure, in turn facilitating creation of minimal viable products which can be further nurtured through support from incubators and ultimately commercialized at scale.

DST has created a portfolio of over 150 Incubators across the country – which are now the hot-beds of innovation and entrepreneurship in India to nurture startups. A recent study by IIT Kanpur on DST efforts on supporting incubators and startups have revealed that the DST programs have impacted over 3 lakhs persons through training, over 2 lakhs of students, 10,000 innovators, over 5500 startups including 500 women startups in the country. The 2889 graduated startups from DST incubators have created more than 1992 IPs, 66,000 jobs, revenue generation of Rs.27,262 Cr and cumulative valuation of Rs. 35208 Cr.

A new variant of startup support model which could be proposed is a distributed model of promoting entrepreneurship by leveraging existing setup of incubators could be initiated in the Hub-Spoke-Spike model to reach out to our expanding base of startups spread across the urban, semi-urban and rural India. This network will have to build upon a strong network i.e Army of mentors pooled across various expertise domains, enabling product market fit, market access, strong investor connect to enhance the funding land scape of innovative solution of startups

India is currently home to nearly 55,000 startups and has become the third-largest startup economy with just the USA and UK ahead of it. Start-ups from India have repeatedly proven their ability to compete with the best in the world. Improved connectivity and increased technology adoption have significantly improved the addressable market in India. Entrepreneurs are increasingly building products across sectors for these markets. From food, travel, sanitation, IT, automobile, aerospace, defense, telecom, AI/ML, Robotics, healthcare, agri-tech Edu-tech, fintech, and entertainment, a new brigade of startups have successfully tapped into lesser-explored chapters. With increasing internet penetration, expanding technology access, and improving the ease with online transactions Indian startups are perfectly positioned to serve challenging but under-tapped markets nationally as well as globally.

Adapting to change and challenges

In order to embark on Science, Technology & Innovation led economy it would be prudent to have a good balance on accelerating innovation of relevance as well as innovation of excellence with clear sense of purpose and robust process of innovation. As a country, we need to focus more on some of the emergent & futuristic areas of research as a directed approach where we want to position India in long term.

To tackle the extraordinary situations created by the pandemic, Indian Science and Tech startups joined forces and came out with extraordinary responses. India witnessed the true power of innovative solutions and entrepreneurship when in a span of three to months many indigenous solutions came in market i.e PPEs, diagnostics kits, critical care Ventilators and contact tracing apps. Along with the startups, the covid crisis also demanded the government to make a considerable departure from previous policies in terms of processes and outcomes. DST as a rapid response rolled out a new program CAWACH (Centre for Augmenting WAr on Covid 19 Health Crisis) in

March end 2020. Total 51 startups with Covid 19, market-ready solutions are being supported and scaled with financial support.

The culture of creative thinking, problem solving, adapting and tackling challenges with agility and collaborating needs to be now embedded in STI ecosystem from the conceptual stage itself.

CONCLUSION

The current post-COVID situation has created a unique opportunity for India to position itself as a manufacturing hub with a big push under 'Make in India' initiative. Towards maximizing the opportunity, our country needs to take measures to improve its production ecosystem and also design new global alignments. For this, proactive, large-scale and integrated measures across all policy areas are necessary to make strong and sustained impacts.

Every country has to find its niche area and technologies. This depends on core competencies, availability of trained and skilled manpower as well as supportive infrastructure, intellectual environment and traditional knowledgebase. It has then to assume leadership in those areas. India has already proved itself to be amongst the top nations in a few areas like space technologies, nuclear energy, IT based solutions etc. We have to maintain this lead. In addition, we have to develop other areas where we have the potential and need to develop technologies on our own. Also the dogma of Science and Technology needs to be graduated to Science, Technology and Economy.

Capacity building and skilling towards adoption of high end technologies, development of machine building capability, customised curriculum to churn out industry-ready manpower, Innovation ecosystem for translation of research findings into product development, focussed attention for fundamental and targeted research, new programs to encourage and nurture out-of-box and blue sky research ideas to ignite young thinkers, robust ecosystem to foster academia-industry collaboration need immediate attention.

The five pillars of AtmaNirbhar Bharat Abhiyan as charted out by our Hon'ble Prime Minister highlights the need for quantum jump in economy instead of incremental. In order to roll out these initiatives it is pertinent to have the road map as well as deeper resource planning to align & enhance the impact multifold. The power of collaboration with industry & stakeholder needs to be systematically harness for realizing the vision of AtmaNirbhar and a new resurgent India.

Change, infrastructure which needs to be designed to suit modern India, a system that is driven by technology which can fulfill the dreams of the 21^{st} century, tapping of demographic dividend, harnessing the strength of demand-supply chain cycle.

To become self-reliant, the linkage between science and society is to be made strong. There should be a mechanism to identify local societal problems and find out their technological solutions. Similarly, a system needs to be created to identify global problems and map them with local solutions.

The new Science, Technology, and Innovation Policy (STIP) 2020 to be unveiled aims to transform the science and tech ecosystem. The new STI policy focusses issues not only at the grassroots level, but simultaneously builds strategic leadership in technology development and Innovation. Further, the STIP-2020 is being developed in strong alignment with the newly launched National Education Policy (NEP) 2020.

Upon strengthening its engineering base through suggestive measures as outlined in the paper, AtmaNirbhar Bharat Abhiyan, India can definitely achieve greater national strides as well as aspire to climb on global leadership.

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Author's Profile

Dr G Satheesh Reddy is well known for his significant contributions towards indigenous design, development, deployment of diversified Missiles & Strategic Systems, Guided Weapons, Avionics technologies and for sustained efforts in advancement of Aerospace technologies & Industries in India. From a young navigation scientist and System Manager he rose steadily and was elevated as Distinguished Scientist in Sep 2014 and was appointed as Scientific Adviser to Defence Minister in May 2015.

He significantly contributed towards the formulation of many national policies and was pivotal in evolving roadmap for self-sufficiency in Missiles. As Director General, Missiles and Strategic Systems (DG, MSS), he spearheaded Dr APJ Abdul Kalam Missile Complex Laboratories - ASL, DRDL and RCI, ITR, TBRL & other technical facilities. As Programme Director, he successfully developed the Medium Range SAMs and achieved a streak of successes in the maiden missions. As Project Director, developed the country's first 1000kg class Guided Bomb and laid foundation for Long Range Smart Guided Weapons. He steered the design and development of indigenous Inertial Sensors, SatNav Receivers, advanced Inertial Navigation Systems for a variety of defence applications including the Ship Navigation.

He holds the distinction of being inducted as Fellow of Royal Institute of Navigation (FRIN), London, Royal Aeronautical Society, UK (FRAeS) and Foreign Member of the Academy of Navigation & Motion Control, Russia. He is an Honorary Fellow of CSI & Project Management Association of India, Fellow of Indian National Academy of Engineering, and IET (UK), Associate Fellow of American Institute of Aeronautics & Astronautics, USA and many other Academies /scientific bodies in the country and abroad. For his distinguished contributions, Dr Satheesh received several prestigious international and national awards and has been conferred with Honorary Degrees of Doctor of Science by many leading Universities in the country.

Self Reliance in Defence

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ABSTRACT

Self-reliance in defence system development is imperative for National Security. The clarion call of the Govt. of India for an 'Aatma Nirbhar Bharat' places greater emphasis on the need for indigenously developed defence systems to secure our borders. This article dwells on the imperatives for achieving self reliance in defence and brings out various initiatives of the Defence Research and Development Organisation (DRDO) towards achieving that objective.

INTRODUCTION

The initiative of the Govt. of India for an Aatma Nirbhar Bharat is based on the concept of making the nation self reliant in all sectors leading to greater economic growth, improved quality of life and thereby a stronger nation in all spheres. A 'reduction in imports' and an 'increase in exports' is seen as the way from trade-deficit to trade surplus. The Aatmanirbhar Bharat Abhiyan initiative focuses on five pillars - Economy, Infrastructure, Systems, Vibrant Demography and Demand. Self reliance in Defence will play a key role in the areas of Economy, Infrastructure and Systems under the Aatmanirbhar Bharat Abhiyan. Self reliance in defence leads to greater national security. The imperatives for achieving self reliance in defence and the various initiatives of the Defence Research and Development Organisation (DRDO) are brought out in the succeeding sections.

DESIGN AND DEVELOPMENT OF DEFENCE SYSTEMS - A PERSPECTIVE

One of the founding objectives of DRDO is to achieve self reliance in defence. Extensive Research and Development (R&D) has been carried out by DRDO for more than six decades to achieve self-reliance in critical defence systems. These systems have significantly helped in securing our borders and making our lives safer.

Self reliance and national security go together. For our nation to gain a decisive edge over adversaries, it is mandatory that state-of-the-art weapons, equipment and systems are designed, developed and produced within the nation. We need to possess weapons and systems with capabilities exceeding those of our adversaries. No other country will share such technologies and systems -they need to be produced indigenously.

India has done well over the past three decades in the development of critical defence systems. We are now self reliant in missiles and missile technologies, and are one of the very few nations in the world to possess such capability. DRDO has developed world class systems that include Agni series of missiles, Prithvi, Dhanush, Brahmos Supersonic Cruise Missile, Akash Surface to Air Missile, Anti Tank Missiles, Radars, Sonars, Torpedoes, Electronic Warfare Systems and Communication Systems, especially the Software defined Radio. We now have the capability of developing our own fighter aircraft, battle tanks and Airborne Early Warning Systems. India is one of the few nations with the Ballistic Missile Defence capability. With the success of the ASAT mission, we are now part of a rare club of countries capable of neutralising a satellite in Low Earth Orbit. These are creditable achievements for a country that has been independent for 73 years. However, we cannot afford to rest on our laurels; a lot more needs to be done.

CURRENT SCENARIO AND ROLE OF DRDO

Despite the development of critical systems, as brought out above, the hard fact is that more than 50 % of the equipment being used by our services is of foreign origin. We are still one of the largest importers of defence systems. Cyber warfare is taking the conflict to a different dimension altogether. Protecting our critical assets from this threat is an immediate need. DRDO has been working on related projects on all levels - tactical, operational and strategic - to safeguard our national interest. Development of systems to obviate all threats - on land, sea, air and cyber is being pursued actively.

Though some systems have nearly 95% indigenous content, we need to take measures to improve indigenous content in all systems, reaching levels of at least 80%. The need of the hour is to identify the gaps in technology and develop crucial and strategic defence systems, by plugging in the gaps. Through the Technology Development Fund Scheme, DRDO funds industry to develop systems that would be inducted into service. The technology related to various systems developed by DRDO is transferred to the industry under the Transfer of Technology Scheme, free of cost. DRDO is also taking steps for exporting DRDO developed systems to friendly nations.

Under the DRDO Dare to Dream scheme, DRDO is encouraging individuals and start-ups to bring out innovative solutions in identified areas. These ideas will be taken to fruition with proper funding and infrastructural support.

AATMA NIRBHAR BHARAT ENABLING TRIAD

The Aatma Nirbhar Abhiyan of the Government of India encourages design, development and production of state-of-the-art systems within India, thereby encouraging in-house capability, and reducing dependence on external sources. This programme would also boost the country's exports and thereby help the economy grow.

For achieving self reliance in defence, the stakeholders in the Aatma Nirbhar Bharat Enabling Triad **(Fig. 1)** need to actively collaborate by pooling in individual strengths synergistically, to achieve the collective goal of indigenous development of systems for the services.

R&D organisations need to specifically work in a focused manner on high-end technologies that require special infrastructure and pooling up of inter-disciplinary / inter-organisation resources. With the early start available to them on account of expertise gained in previous projects; these organisations can leap-frog to meet futuristic needs. These organisations also need to evolve roadmaps projecting into the next 50, 25 and 10 years, identify the technological and infrastructure needs and acquire the necessary know-how and know-why.

Academic institutions have a great role to play in this endeavor. The academia needs to work on basic research in nascent technological areas, and put in place the necessary scientific methodology required for translating the technologies into

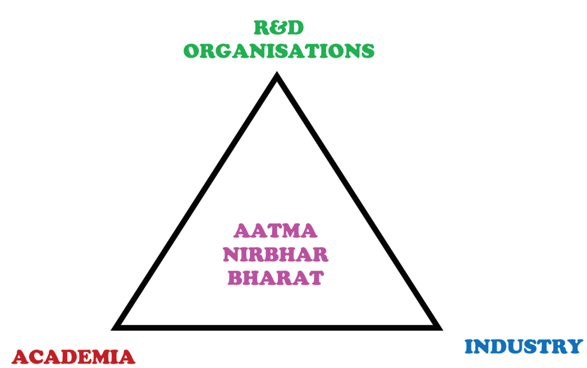

Fig. 1 : Enabling triad for Aatma Nirbhar in defence

tangible products and systems that can be deployed by our armed forces. Academic institutes must become the hubs for fostering innovation and entrepreneurship. Dedicated laboratory spaces must be created in collaboration with research institutes to enable students get valuable experience. Joint programmes must be formulated with other academic institutions and research organizations to propel research in identified areas. Focus must be laid on setting up incubation, innovation and research centres within the campus for studies on futuristic areas of technology. Proper mentoring by experts as and when needed must be provided.

As regards the third component of the triad, the industry must not be content with production of systems as per specifications. They must also focus on in-house R&D with small teams to work on relevant, niche areas. Industry must collaborate with foreign entities for development of systems for which know-how is not available within the country. Industry must develop export-ready systems that are of best quality at competitive costs.

When all the stakeholders in the triad work hand-in-hand, with sustained and focussed efforts, it will be possible to effectively strengthen the technological base of the country. The technological edge thus gained will give our country a decisive edge over our adversaries.

WAY AHEAD

The culmination of basic research, applied research and translational research with collaboration of R&D institutes, academia and industry will lead to self reliance in defence, and thereby, propel all-inclusive growth.

'Mission Shakti' was the result of the deployment of a number of path-breaking technologies which were developed by joint efforts of scientists and technicians, academia and industry. This mission made our country only the fourth in the world possessing such capability. The expertise gained and the lessons learnt from such endeavours stand testimony to our collective strength, and will serve as role models for our future activities.

When we work together, with focus, we will definitely succeed. Technologically strong, first-of-their kind systems will help build stronger borders, and thereby a prosperous nation.

Aatma Nirbhar Bharat Abhiyan will lead to self reliance in defence, which will in turn result in a *Shaktishali Bharat of Today, Tomorrow and Forever*.

Author's Profile

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Shri Vinod Kumar Yadav, Chairman and Chief Executive Officer (CEO), Railway Board & Ex-Officio Principal Secretary to Govt. of India, an electrical engineer belongs to the 1980 batch of Indian Railway Service of Electrical Engineers (IRSEE).

Shri Yadav began his career on Indian Railways as Assistant Electrical Engineer in February, 1982. He has an illustrious career in Indian Railways and has worked at key positions before being elevated to the post of Chairman of Railway Board on 01 January 2019. He has held various assignments on deputation also including that of Executive Director (Electrical), RVNL, Group General Manager (Electrical), DFCCIL, Project Director, International Centre for Advancement of Manufacturing Technology at United Nations Industrial Development Organization (UNIDO), and Director, Department of Industrial Policy & Promotion, Ministry of Industries, Government of India. He also held an important foreign assignment in Turkey, where he was instrumental in Planning, execution and Commissioning of Railway Electrification Project for Turkish Railway.

He holds immense experience in the fields of Project Management, General Management; Industrial Policy Formulation, Foreign Collaboration & Foreign Direct Investment; Management of Sector Specific International Technical Programmes and Co-ordination of World Bank and Japan International Cooperation Agency (JICA) Funding.

Under his dynamic leadership Indian Railways has achieved many milestones in introducing reforms aimed at transforming Indian Railways into a vibrant organization. He has given a big push to infrastructure development & capacity creation, increasing railway's modal share in freight, digitalization of various processes and improvement in quality of both freight and passenger services. Recently, Railway Board has been reorganized on functional lines as part of organizational reforms and Shri Vinod Kumar Yadav has been appointed as the first Chairman & CEO of the restructured Railway Board and assumed charge from 2 September 2020. Shri Yadav is the Fellow of The Institution of Engineers (India) and Fellow of The Institution of Engineering & Technology (UK).

Indian Railways: On the Path of Modernization

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Photo: Goods train running on the eastern arm of Bhadan - Khurja section of Eastern dedicated freight corridor

Indian Railways (IR) is the lifeline of the country. IR acts as the engine of Economic Growth by providing safe, financially viable and environmentally sustainable mode of transport for freight as well as passengers. IR has played a crucial role in national integration and social binding by providing rail connectivity to the far-flung areas across the country. IR is the third largest Railway in the world under a single management after Chinese and Russian Railways and is in the club of top 4 Railways moving over one billion tonnes of freight on an annual basis viz Railways of USA, China, Russia and India. IR is the number one Railway in the world in terms of Passenger Kilometer moved annually.

Over the past years, IR has experienced a steady decline in market share. The rail freight modal share has declined from 89 per cent in 1951 to nearly 25 per cent in 2018-19. This is mainly because rail infrastructure and capacity creation have not kept pace with traffic growth and over a period of time traffic has moved from rail to road and other modes. The Railway route kilometer has increased by nearly 30 per cent and track kilometer by 60 per cent in 70 years after independence while passenger and freight transportation output has increased over 16 times.

Lack of capacity creation and modernization commensurate with traffic growth have led to network congestion and reduced speeds of trains. This fall in modal share of rail, is not desirable from both economic efficiency as well as environmental sustainability and social considerations. Railways is highly energy efficient mode of transport besides being safe, and requiring very less resources including land, and needs to be a dominant and preferred mode of transport.

Movement of passenger and freight trains on the same tracks with high speed differential drastically reduces capacity and speeds. As per National Transport Development Policy Committee (NTDPC) Report of 2014, out of 1,390 sections on Indian Railways, 480 sections have capacity utilization exceeding 100 per cent and 738 sections have capacity utilization exceeding 80 per cent. Seven routes of High Density Network (HDN) and eleven routes of Highly Utilized Network (HUN) amounting to ~34,000 Route Kilometer (RKM) (~ 51 per cent of network) carry nearly 96 per cent of IR's traffic.

This trend needs to be reversed and Railway's modal share in freight needs to be increased to over 40 per cent. Railways is moving to tackle these legacy issues through higher investment in infrastructure development and modernization and focusing on better services to customers. This is being achieved through a mindset change by ushering in a culture of "speed, scale and skill", and embracing organizational restructuring. Railways is working to make permanent, transformative changes that will provide world class transport options for the country. Indian Railways' Vision is to become a self-sustaining organization by 2024 with a focus on safe, swift, punctual, efficient & cost-effective customer services, technology driven modernization, aggressive jump in freight share at competitive prices, improved passenger services and streamlined management & transparent functioning.

Since 2014, Railways has incorporated certain core management principles in its work by taking a holistic approach on each issue and this has helped in steadily and systematically transforming the seemingly impossible into the possible. These include - Root Cause Analysis, Partnership with all stakeholders, Decisive leadership, Outcome oriented action, Rule of law & transparency, Prioritization of issues, Time-bound execution and fast dispute resolution, Innovative Financing, Technology Focus, Accountability & close monitoring.

Following the mantra of 'Reform, Perform & Transform' given by Hon'ble Prime Minister, Railways has set itself stiff and impossible looking targets, be it the elimination of Unmanned Level Crossings (UMLCs), railway electrification, production of locomotives and coaches, provision of bio-toilets in coaches, installation of Railway Over Bridges (ROBs)/ Road Under Bridges (RUBs)/ Foot Over Bridges (FOBs), or high speed Wi-Fi at railway stations. Each of these areas has witnessed a remarkable increase in performance. The lofty targets have set the bar high, and have enthused Railways to scale higher peaks than ever before pushing its own limits. As a result, there has been a visible change across the Railway network.

SAFETY-THE TOP MOST PRIORITY

With constant focus on safety, IR has achieved the best ever safety performance in FY 2019-20. Consequential train accidents have progressively reduced from 135 in 2014-15 to 59 in 2018-19 and further to 55 in 2019-20. For the first time ever, since April 2019, there has been no passenger fatality in train accidents. This was achieved through various safety measures undertaken in mission mode.

Unmanned Level Crossings (UMLCs) have always been a major contributory cause of train accidents involving road users. IR accelerated the removal of UMLCs and eliminated all UMLCs on Broad Gauge by January 2019. For the first time ever, a Rashtriya Rail Sanraksha Kosh (RRSK) was created in 2017 with a corpus of Rs.1 lakh crore to be spent over five years to clear the accumulated backlog of critical safety related works especially targeted at the root cause of accidents mainly derailments and accidents at unmanned level crossings. The health of the tracks and bridges is a major factor for safety. Renewals of tracks have been prioritized to clear the backlog of rail renewal. IR has completely switched over to manufacturing of Link Hofmann Busch (LHB) coaches from January 2018 onwards. LHB coaches are safer than Integral Coach Factory (ICF) coaches and sustain lesser damage during accidents. LHB Coach production has increased 11 times in 6 years from 543 coaches in 2013-14 to 6,277 coaches in 2019-20.

In a visionary plan, to further enhance safety of train operations, it is planned to install indigenous Train Collision Avoidance System (TCAS), developed in 2017 on entire Railway network in a phased manner giving priority to busy routes. System is already functional over 250 route km and will be proliferated over the entire network in a phased manner. The work is in progress over 1,200 route km. Further, a paradigm shift is being brought to maintenance practice for rolling stock from time-based maintenance system to condition based predictive maintenance. Thrust is also being given to simulator based training of locomotive pilots.

INFRASTRUCTURE CREATION & NETWORK EXPANSION

Government has recognized the need for additional investment in rail infrastructure and modernization and progressively scaled up investment in Railways by almost 3 times from Rs 54,000 crore in 2013-14 to Rs 1.46 lakh crore in 2019-20. The increase in capital expenditure and improved project management has increased the speed of commissioning of new infrastructure projects.

A National Rail Plan (NRP) 2030 has been developed with a view to develop infrastructure by 2030 to cater to the traffic requirements upto 2050. Based on the NRP, a Vision 2024 document has been issued to develop infrastructure by 2024 to enhance modal share of Railways in freight transportation to more than 40 per cent and to cater to the traffic requirements upto 2030. Vision 2024 document lists all priority projects with target dates of completion and allocation of resources. Multi tracking of 14000 km route, electrification of entire Railway network, upgrading the speed potential of important routes to 130 kmph and 160 kmph (present speed potential 110 kmph), completion of important coal connectivity and port connectivity projects have been planned as part of Vision 2024. An innovative financing has been devised to fund these priority projects. Indian Railway Finance Corporation (IRFC) is mobilizing resources with sufficient moratorium period and projects are being targeted to be completed well before expiry of moratorium period. These priority projects are being planned in such a way that they will provide enough return to service the debt.

Decision-making processes for appraisal and approval of projects and sanction of estimates have been streamlined. Powers have been delegated to field officers to speed up decision making. A standardized Engineer Procure Construct (EPC) document has been adopted. E-DAS (Electronic Drawing Approval System) has been introduced to fast track approval of drawings. As a result of the above measures, annual pace of commissioning of new lines, doubling/tripling/quadrupling (multi-tracking) and gauge conversion have increased significantly.

To rapidly provide rail connectivity to Jammu & Kashmir, big thrust has been given to Udhampur-Quazigund-Srinagar-Baramulla rail line project (USBRL). Out of total length of 272 km, 161 km is already commissioned (Udhampur- Katra and Banihal- Baramulla) and work is in full swing in the remaining 111 km section from Katra to Banihal. The project is targeted for commissioning by December 2022. USBRL project has many engineering marvels like,

a. highest arch bridge project in the world at Chenab (359 meter from river bed);

b. first cable suspended rail bridge in India (290 meters from river bed); and

c. longest transportation tunnel of India, Pir Panjal (12.75 km).

Photo: Artistic view of bridge being built across river Chenab

Connectivity of the North-East part of the country is a major thrust area. Entire rail network in North East region has been converted to Broad Gauge and all North Eastern States (Assam, Meghalaya, Nagaland, Tripura, Mizoram, Manipur and Arunachal Pradesh) have been connected with rail except for Sikkim where work is in progress. Further, it is planned to connect the 8 capital cities of all North-East States with IR's network. Capital cities of three States (Assam, Arunachal Pradesh & Tripura) have been connected and works are in progress for the remaining five (Manipur, Mizoram, Nagaland, Meghalaya & Sikkim).

Photo: Jiribam-Imphal national railway project: bridge no. 44

DEDICATED FREIGHT CORRIDORS

Eastern and Western Dedicated Freight Corridors (DFC) are projects of national importance and critical to IR to have an aggressive jump in freight volumes over the next 3-4 years. These DFCs will be modern and efficient heavy haul corridors with long freight trains running at 100 kmph and with double stack containers under high rise Over Head Equipment (OHE) in Western DFC. DFCs will help in the rapid, seamless and easier flow of goods and give a boost to economic development, create more jobs and connect factories and farms to ports.

The project has been taken up in a Mission mode. 500 Route km of DFC comprising of Rewari - Madar (306 km) section of WDFC and Khurja – Bhadan (194 km) section of Eastern DFC have been completed in FY 2019-20. Another 500 km section will be commissioned by March 2021. Freight trains are running on the sections, which have been commissioned. With 40 per cent of DFC network connecting Gujarat ports, freight traffic from Gujarat ports will be shifted to Dedicated Freight Corridors after commissioning of Rewari – Palanpur network in March 2021. The entire DFC project is targeted to be commissioned by June 2022.

Photo: Ultramodern operation control centre of DFC at Prayagraj

Further, Detailed Projects Report for 3 new Dedicated Freight Corridors of 4,000 km viz East Coast DFC from Kharagpur to Vijaywada, East - West DFC from Bhusawal-Nagpur-Kharagpur-Rajkharsawan-Andal-Dankuni and North - South DFC from Itarsi to Vijayawada are being prepared.

VISION OF A GREEN RAILWAY

In line with India's vision to reduce emission intensity by 33-35 per cent by 2030, a decision for 100 per cent electrification of broad gauge Railway Network has been taken by Railways and a challenging target of being a completely electrified network by 2023 and net-zero emitter of carbon by 2030 have been fixed.

The speed of electrification has been greatly scaled up from a level of 1,176 km in 2014-15 to 5,276 km in 2018-19. 18,065 km of Railway Route was electrified during 2014-20 as compared to 3835 km during 2008-14 recording unprecedented growth of 371 per cent.

Under the 'Make in India' initiative, Railways is scaling up the work of land based solar panels which will provide power for traction purposes. It is planned to generate 3 Giga Watt solar energy for IR in the next few years and install a total of 20 Giga Watt solar plants over the coming years on vacant railway land to meet the full traction energy requirement.

Photo: Solar panel installed at Howrah railway station

HIGH SPEED RAIL (MUMBAI – AHMEDABAD)

The visionary Mumbai – Ahmedabad High Speed Rail project being executed by Railways in collaboration with Government of Japan will herald a new era of safety, speed and service for the people and help IR become an international leader in scale, speed and skill. 67 per cent land required for the project has been acquired and contract packages covering 325 km length of viaduct and 05 stations in Gujarat, worth Rs 32,000 crores have already been awarded.

MAKE IN INDIA – ATMANIRBHAR BHARAT

The import of material by Indian Railways has significantly reduced to the level of 1.5 per cent from 6.5 per cent in last 6 years. With setting up of manufacturing facilities for wheel, axle and track machines in India, requirement of import will almost be eliminated. IR has developed its own Automatic Train Protection system in 2017, semi high speed train set in 2018 and high horse power locomotive of 12,000 HP in 2019. Made-in-India Train Collision Avoidance System (TCAS) has been adopted as a national Automatic Train Protection (ATP) system to enhance safety and speed of Railways.

Photo: 12,000 high horse power locomotive

FREIGHT - MOVING INDIA'S ECONOMY

Across the world in all large sized countries, Railways is used as a major mode of transport for freight. Historically, this had been the case in India as well, but gradually, due to various shortcomings Railways started lagging. While Policy distortions led to overpricing of freight to subsidize the already low passenger fares, and privileging the ever-increasing passenger trains that steadily elbowed out freight trains leading to steady erosions of modal share. Now, Railways have embraced a "Freight on Priority" policy by pushing for an aggressive customer-centric approach to expand the freight carried not only from the traditional segments but also by attracting new customers to its fold.

In FY 2020-21 Business Development Units (BDUs) have been set up at Railway Board, Zonal Railway and Divisional levels. Multi-disciplinary teams from BDUs have been reaching out to customers to attract new business by providing compelling value-for-money logistics solutions. The BDUs have scored several early successes by attracting new business from customers who had never used rail in the past. A large number of freight incentive schemes have been launched and non-tariff liberalization measures have been undertaken to improve the customers' experience with the Railways. New initiatives launched in this year include the Time-tabled parcel services to provide reliable services to courier services & e-commerce companies. Kisan Rail Services have been introduced to enable farmers to send their produce across the nation with enhanced speed & reduced cost. With all these initiatives, Railway's freight has staged a remarkable recovery with the freight loading in September and October 2020 showing a growth of 15 per cent over last year.

The real reform in the freight rail is not the early success in incremental freight loading but a culture of continuous engagement with the customers at every level including at the level of Ministry of Railways. The objective is to deeply embed this culture across the Railway Organization so that winning customer loyalty becomes a habit.

The gains in freight, in the near-absence of passenger services, is being institutionalized by a novel and radical reform in time-tabling of trains. Instead of the age-old philosophy of prioritizing passenger trains in an incremental fashion, the zero-based time table has looked at the holistic picture and has provided dedicated time corridors for freight and passenger services besides earmarking separate corridors for assured maintenance of assets. By grouping and coalescing trains with similar speed characteristics and adopting a hub and spoke approach, zero-based time-table will lead to conflict-free running of optimum number of trains, vastly increasing the number of freight paths available. Zero-based time-table exercise is nearly complete and shall be launched shortly.

STATION DEVELOPMENT & MODERNIZATION

Upgradation of 68 railway stations has been completed since 2018 to improve passenger experience and convenience. The major works include improvement of façade, platform resurfacing, enhanced illumination, improvement in circulating area and facilities for Divyanjana. Station redevelopment work is in progress at Gandhinagar, Habiganj, Ayodhya and Gomti Nagar. Railways is now taking a partnership approach for station development and RFQs have been invited for New Delhi, Chhatrapati Shivaji Mumbai Terminal, Nagpur, Gwalior, Sabarmati, Amritsar, Pudducherry, Nellore, Dehradun and Tirupati stations on PPP mode.

ENHANCING PASSENGER CONVENIENCE

Hassle-free ticket booking has been facilitated through mobile apps and digital payment. SMS service, to relay important travel related information, has been provided to passengers free of cost. This has eliminated the need to come to station hours in advance and helped them stay informed. Sufficient escalators and lifts have been provided at railway stations to provide convenience to passengers especially Divyanjan, elderly, pregnant women and children. All railway stations have been provided with LED illumination. Further, improvement in illumination levels has been done at over 800 railway stations. This has not only improved visibility but also the safety of passengers. LED lighting is also cheaper and greener than conventional lighting. Over 5800 railway stations have also been provided with free Wi-Fi since January 2016.

Mobile Apps like Coach Mitra, Rail Madad and Yatri Mitra have been launched to empower the passengers to seek immediate attention of authorities for availing services on running trains, ask for wheelchairs / porter services at stations and report their grievances respectively.

Further, for the first time ever, unreserved booking has been enabled through a mobile app, providing convenience for passengers especially in crowded suburban areas like Mumbai. People now do not need to stand in queues at the station.

Photo: Vistadome coach running on Visakhapattnam-Araku route

NEW SERVICES IN PASSENGER OPERATIONS WITH PPP IN TRAIN OPERATIONS

Railways is now undertaking a partnership approach for passenger train operations. To enhance overall service quality and operational efficiency, IR is now pro-actively engaging with stakeholders and initiating dialogue with private players. This aims at improving the passenger experience and bringing modern technologies and private investments.

In the first phase, it is planned to introduce 151 modern passenger trains operated through PPP over 109 Origin Destination (OD) pairs of routes. This will bring private sector investment of Rs. 30,000 crores. Applications from interested parties have been received and Request for Proposals (RFP) has been issued to shortlisted applicants in November 2020.

SWACHH BHARAT SWACHH RAIL

Swachh Bharat has acquired the stature of a mass movement in India. Along with the citizens, Railways too has contributed to this national movement in a big way. 100 per cent coaches have been fitted with bio-toilets.

Photo: Bio-toilet fitted in coach

This has eliminated open defecation on tracks. This contributes to a more hygienic environment on the railway tracks and in the stations. It also has a direct impact on safety & life span of iron structures by reducing chances of corrosion due to human waste. With a view to improve the standard of cleanliness, Mechanized Cleaning of stations and trains is being carried out through professional agencies.

Photo: Mechanized cleaning of stations

The Ministry of Railways' efforts have been adjudged as the best by a Ministry for implementation of Swachhata Action Plan and the Ministry was awarded for this by the Hon'ble President of India in September 2019.

Organization Restructuring: Making Railways Astute, Agile & Assured

A radical reform in Organizational Restructuring has been undertaken in 2019 to break down departmental silos and develop an overall perspective in all aspects of Railway working.

The size of the Railway Board has been reduced and Board has been reoriented on functional lines. It has also been decided to unify the 8 Organized Group 'A' services into one service viz., Indian Railway Management Service (IRMS). The modalities for recruitment of officers into IRMS and unification of the existing services are being worked out. This has been recommended by a number of Committees in the past but was never attempted over fear of the complexity of managing the transition. This has been done now after broad-based consultation with officers to prepare them to transform Railways into a truly world-class Organization

DIGITAL INDIA - TRANSPARENCY IN ALL FACETS

Bringing transparency and accountability by leveraging digital means is a major thrust area. Railways has ushered in a new era of transparency and digitization in all aspects of its work, especially for procurement and accounts

All tenders of Railways (works or stores) have been put on e-tendering platform (Indian Railway Electronic Procurement System - IREPS). Electronic reverse option has been introduced in the stores procurement for tenders above Rs. 5 crores and works and services tenders above Rs 50 crores. Railway Recruitment Boards (RRBs) have adopted IT based online format in a big way. Computer based tests were introduced in the year 2015 and since Aug 2015 all examinations of RRBs have been conducted online.

Rail Drishti Portal has been launched in 2018 as an information portal that provides key details from various sources on a single dashboard. Users can visit the portal for information related to passenger reservation, unreserved ticketing, freight earnings and freight loading. The portal offers access to PNR enquiry, complaint enquiry, tender enquiry, shramik enquiry and freight related enquiries. It also has a facility to track any train on the IR network and obtain the contact number of housekeeping staff on the train. By providing access to every citizen of the country it has helped to promote transparency in all facets of Railway working.

Satellite based 'Real Time Train Information System' (RTIS) has been developed in collaboration with ISRO. RTIS has been installed on 2,700 electric locomotives. Through this project, the real-time location and speed of trains are being captured every 30 seconds and is conveyed to Control Office Application (COA) and also to passengers through National Train Enquiry System (NTES). This has resulted in Automatic Charting of trains and thereby relieving the controllers to concentrate on the important operational tasks. In phase-II remaining electric locomotives will be provided with RTIS equipment. This is a vital step forward to track precise location of trains and analyze train movement data for improving mobility and operational efficiency of Railways.

INDIA'S FIRST NATIONAL RAIL & TRANSPORTATION UNIVERSITY IN VADODARA

To develop talent & skills for the transport sector, the National Rail & Transportation Institute (NRTI), has been set up. This has been envisaged as a Central University & Institute of National Importance. NRTI is India's first multi-disciplinary University focused on the transportation sector. NRTI's first Academic Session (2018-19) commenced on 5 September 2018. NRTI also helps foster innovation, entrepreneurship and supports Start Up India initiative. A total of 200 students are presently enrolled at NRTI. Two new B.Tech Programs and six new Masters Programs have also been launched in addition to the two undergraduate degree programs from this Academic Year (2020-2021).

Indian Railways continues to work steadfastly to become the engine for the country's economic growth. Over the past few years, Railways has strived for modernization of systems, processes and infrastructure. Railways is committed to become an efficient, cost effective, punctual and a modern carrier of passengers as well as freight in order to serve the growing needs of new India.

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Author's Profile

Dr Anil Kakodkar spent a full professional career in India's atomic energy program with nine long years in the apex leadership role. India's atomic energy programme saw significant transformation and boost through contributions and leadership of Dr Kakodkar. Post-superannuation,Dr Kakodkar continues to be active in several aspects of energy, education and societal development. Development of CILLAGE concept for sustainable bridging of urban rural divide being one among them.

Engineering a Capable, Sustainable and Responsible India

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INTRODUCTION

India would soon be celebrating 75 years of her independence. During this time, the country has emerged as the largest democracy, second largest (and soon to be first) populated and one of the largest markets where the vendors of the world make a beeline. India is now one of the largest economies (specially in $ppp terms) and geopolitically a very important country. The country has been steadily expanding her infrastructure in almost all sectors making her one of the largest producers of agriculture/horticultural products, electricity, coal, steel etc.; one of the largest roads and railway network, IT and communication industry, entertainment (particularly cinema) industry etc. In GDP terms, service sector contributes to more than half of India's GDP with industry sector contributing around a third (half of it by manufacturing sector) and agriculture sector contributing about a sixth. Indian diaspora (and India continues to be the largest country of origin of international migrants with a 17.5 million-strong diaspora across the world) contributes to around 3.4 % of India's GDP by way of their remittances. This amounts to nearly double contribution to India's economy in per capita terms.

While this growth and development story is indeed impressive for a large and diverse democracy like India, the growing disparities in the country are alarming. Since the 1980s, the income share of the top 1% of the population has been rapidly rising, reaching 22% for the most recent year for which estimates are available1, around a half of this income being concentrated in the top 0.1%. This has led to disproportionate amassing of wealth in the top layer with little trickle down. In the rural domain, where larger population of India resides, while the average per capita income is nearly a half as compared to urban domain, the Gini index of income is actually higher. The index is rising in both rural and urban domains. Besides economy, the disparities in terms of access to basic needs are also alarming. Take health sector for example. While India boasts of world class facilities that attract medical tourism, our ranking in healthcare has slipped to 150th place according to a recent report brought out by World Economic Forum. The severe financial distress being faced by even middle-class families who had to access medical services during the current pandemic is another pointer to severe disparity that exists. Our Human Development Index still stands at around 129 while our neighbour Sri Lanka is at 71.

Clearly, while wealth creation should remain an important objective, efforts towards creating a more equitable, harmonious, stable and humane society must be given equal if not more importance. The discordance between the two beyond a limit could lead to serious cliff edge situations arising out of unbridgeable aspiration gaps. Dealing with climate crisis, depleting natural resources crisis, local and regional environment degradation and such other triggers for tail end risks in the society can be handled with much greater resilience in a harmonious and equitable society than in a society that has high disparities.

Witnessing distress reverse migration of crores of daily wage earners from the very cities that have been providing them with livelihood, despite authorities promising shelter and food, during the recent lockdown, has been a very distressing and a stark example of such situations that were witnessed during the ongoing pandemic. Many even resorted to walking back to their villages/ home towns hundreds of kilometres away as their continuing in cities with no jobs in hand, became untenable.

THE CHALLENGE

Covid-19 pandemic has led to a lot of rethinking about socio-economic framework that we have woven around us and its consequences during normal as well as abnormal times. Everyone is talking about the new normal that is expected to set in the post pandemic period, although the visualisation of that new normal seems to vary dependant on the lens one has put on. Some scenarios that we have witnessed in recent times have however been very disquieting. Human to human connect is tending to be more virtual than real so much so that some succumbing to the virus have had to embark on their last journey without their near and dear ones anywhere around them. The list of such troubling scenarios thrown up by the pandemic is long.

Humans, in contrast to all other living species on the earth, possess special abilities to think and innovate. While there is bound to be some diversity in the abilities of individuals in this context, the fact remains that the socio-economic environment in which humans grow and the experiences they go through, largely determine the capabilities and behavioural patterns that the individuals develop. It is thus important that everyone, without any active or passive discrimination, gets a conducive environment to learn, develop and become a capable and responsible human being. Unfortunately, the reality is quite different and there is a wide variation in the opportunities to learn and build capability as a result of non-universal access to relevant facilities or the absence of the right eco-system. Villages are particularly at a disadvantage in this context. The capable ones as they progress in life tend to become a part of an exploitative framework leading to the exploitation of the weaker fellow human beings, knowingly or unknowingly. The same framework also leads to disproportionate degradation of nature and exploitative depletion of its resources much to the disadvantage of the vast majority in the society. The human intelligence while leading to a smaller part of this world becoming a better place, has not fully contained the human greed or the animal instinct in humans. Large disparities seem to be the result while the earth rapidly approaches the tipping point. Social and economic frameworks that have got built around us have only contributed to this exasperating situation rather than ameliorating it. It takes extreme events like the pandemic to bring home the bitter truth related to the disaster in waiting. Covid-19 pandemic has exposed the fault lines in our society in a very stark fashion. It seems to me that Gandhiji had broadly visualised this situation while developing the societal framework for independent India and had in fact comprehensively experimented with concepts like ‘sarvodaya’ and ‘gramodaya’. Unfortunately, we have not adequately listened to him. Disparities have become broader and deeper in the form of divides such as rich-poor, urban-rural etc. as a result, even as the economy grew.

THE SOLUTION

The socio-economic instabilities seem to be arising because of several factors. A larger segment of humanity has been left behind for want of adequate access to meaningful education, capacity building and ability to leverage increasingly complex technologies. As a consequence, a significant asymmetry in the value addition capabilities of different segments of the society seems to have taken place. We seem to have created a rather unrestrained access to markets everywhere without being too much concerned with creating a level playing field for all segments of society to be empowered with competitive value addition capabilities. This has led to further exasperating the situation.

A larger segment of Indian population still resides in villages. The efforts to re-engineer the country should thus primarily focus on rural India. In the knowledge era that we are fast embracing, we should recognise that knowledge technologies actually promote democratisation and decentralisation. 'Work from home' which has emerged as a new norm in the knowledge era could also mean 'work from villages' if there is sufficient capacity building through education, skilling/ training and entrepreneurship development in the rural domain. Rather than limiting value addition in rural areas to agriculture and allied activities, villages can also make major contributions in service sector as well as in manufacturing sector. The larger segment of Indian population can thus access the potentially greater opportunities in villages leveraging the possibility to 'work from home in villages' and be a more powerful engine of growth while reducing the disparities to a large extent. While doing so we must not forget to pay attention to human development aspect to steer the transformation towards creating a more equitable, harmonious, stable and humane society in a sustainable way. Similar arguments apply to capacity building efforts among people at the grass roots in other categories. Further, we should simultaneously encourage better opportunities to higher performing groups and link them with the process of capacity building of the people at the grass roots.

THE CILLAGE[2]

It is thus clear that the key to redressal of the present situation lies in insightful attention to capability building of human resource in villages and make villages centres of competitive value addition in a comprehensive way. Individuals in villages should become engines of growth not just in agriculture and allied activities but also in other segments of economy such as service and manufacturing sector. Technology is clearly the key to multiply human capability. However, the adoption of technology should be done in a manner that that does not become exploitative and maximises near uniformly distributed collective output. Teachings of Gandhiji interpreted in today's context have become most relevant in this context specially in regards to 'Grama swawalamban' – village self-reliance. As discussed above, in the contemporary knowledge era, this should produce even more spectacular results than what was possible during the time Gandhiji propagated these ideas. In addition to agriculture and allied activities, where villages have a natural advantage, one could significantly bring in major economic activities leveraging digital and newly emerging exponential technologies including decentralised manufacturing in villages much the same way as they take place in cities. Technology access, training/skilling as well as capacity building; education, research and new technology development; and a holistic eco-system in villages encompassing knowledge, technology, livelihood and mutual human sensitivity would however be a pre-requisite to creating such higher opportunities in villages. We need to convert villages into small and vibrant human settlements of a Digital Society of 21st Century. I call them a Cillage that incorporates the best of a city in a village. A cillage is a knowledge-based ecosystem for integrated education, research, technology development and deployment as well as livelihood and capacity building in rural areas. Going forward the Cillage should become - a Digital City in a Modern Village. Such a cillage would be self-reliant, in fact a net exporter and competitive with no fear of job losses in the wake of an onslaught of new technologies. With bridging of the divides that cillages would bring about, we should be able to move towards a stable and humane society free from instabilities.

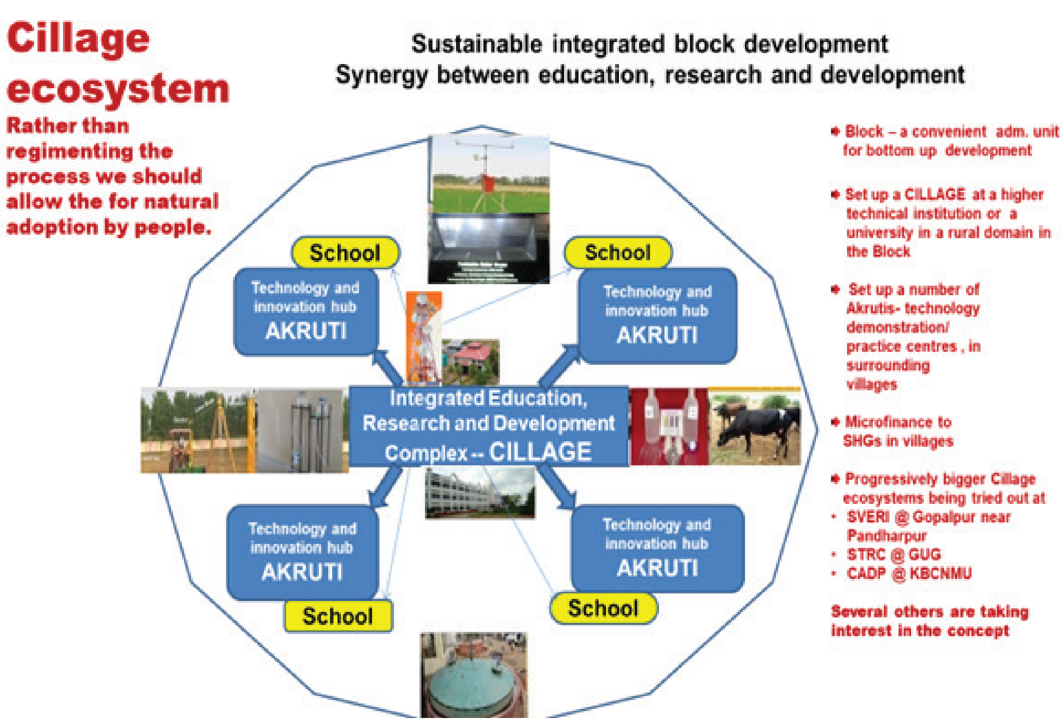
How do we build such a cillage eco-system starting from where we are at present? Clearly this challenge is not about building brick and mortar infrastructure, rather it is about people, particularly about change in mind set of people, that makes them humble rather than arrogant with their realising higher capabilities. Their enthusiastic working together leveraging their diverse capabilities to complement each other into a win-win co-operation should move the entire rural domain towards higher level of competitiveness. We need to facilitate a variety of comprehensive engagements between local stake holders and allow these to sink in for people to explore robust and sustainable practices. Typically, we would need following types of engagements {examples as have evolved in actual practice are also mentioned};

1. Between technology and people wanting to enhance their livelihood leveraging the technology. This should include demonstrations, training/skilling, entrepreneurship support and market access. There is an extensive akruti (advanced knowledge based rural technology initiative) programme initiated and being propagated by BARC in this context. Similarly, technologies related to aquaculture, bamboo craft and NTFP/medicinal plants sourced from other agencies are at work for enhancing livelihood in Gadchiroli region.
2. Between local knowledge institution/s and the neighbourhood to internalise new technologies, understand the problems during their implementation and keep technologies rejuvenated through R&D. Going forward, local R&D capabilities must grow to be able to create new technologies to address local problems leveraging new scientific knowledge. Alongside locally relevant academic programs should also evolve to address the needs of local livelihood and related linkages. Progressively, colleges and universities such as SVERI, GUG and KBC NMU are taking such initiatives forward. The idea is gaining ground and is being pursued by several other individuals and institutions.
3. Between technology enabled schools, natural surroundings and the socio-economic practices around. While akrutis described in para 1 above bring members of society and technologies together for enhancing their livelihood and colleges and universities described in para 2 above bring technologies and knowledge together (both with respect to education and research), bringing together schools and socio-economic practices around enables children (tomorrow's citizens) to better understand the challenges and the opportunities in the society and assemble their learning accordingly. This should constitute a major enrichment in their education. Existence of contemporary technology practices in the neighbourhood that remain at the state of

art level as a result of local research culture, not only help locals to sustainably remain competitive in terms of their livelihood but also expose school children to situated learning and connect them with relevant skills and local opportunities leading them to be well rooted in the local surroundings with respect to their livelihood ambitions.

Today schools in rural areas face serious challenges in terms of resources, need to handle large numbers and digital access to rest of the world. In co-operation with organisations like MKCL, NKN, IITB, HBCSE and SVERI, a project shikshan pandhari on secondary school education was implemented with a few schools in remote locations for development and delivery of open education resources through appropriate low cost technology solutions. During the recent pandemic we are witnessing the tremendous challenge to school education in rural areas despite technological advancements simply because the process of adoption of these technologies is driven by vendors rather than by people who understand education and learning. Shikshan Pandhari has been a valuable experience in this regard. We obviously have miles to go to leverage technology to address the issue of access for large number of school children as well as the quality of education with the infrastructure and resource limitations that we have. Simultaneously we should think about integrating this into a comprehensive eco-system comprising of the discussion in paragraphs 1, 2 and 3. This is of crucial importance to India's competitiveness going forward. We must quickly recognise that the future belongs to digital/exponential technologies. We must prepare our rural children to be able to be deal with exponential technologies as competently as other children around the world. This needs comprehensive efforts even at school level.

There is also a need to reorient teachers to be effective in terms of the needs of the new age society. Yashwantrao Chavan Maharashtra Open University together with MKCL knowledge foundation have already put in place a PGDEEDS (Post Graduate Diploma in eEducation in Digital Society) programme for this purpose.



The above somewhat elaborate description of the evolution of cillage ecosystem needs sustained participation of all stakeholders including local communities. There should be enough scope for leveraging available opportunities to make a start and progressively reach the holistic eco-system. Rather than regimenting the approach to this evolution the effort should be to let the cillage network evolve organically leaving enough space for local innovation for developing the individual nodes as well as the linkages of the network. The aim should be to transform our society from being just transactional to an entrepreneurial one where there is a joy of creation through value addition. Having said that, I would imagine that universities and colleges in rural domain should primarily take it up upon themselves to catalyse such an ecosystem in their neighbourhood.

HIGHER EDUCATION

A word about higher education would be in order at this stage. There are several aspects to objectives of higher education. The most important among them to my mind relates to making India globally competitive. A country of the size of India needs many universities that are similar in scale, scope and level of excellence as Stanford, MIT, Harvard, (and Nalanda of ancient India) to take it forward. For example, Stanford University, as a case study, consistently ranks in the top 5 of global rankings. Its 2000+ award winning faculty members include 17 Nobel Laureates and spans multiple disciplines such as engineering, law, business, sciences, arts and humanities, and medicine. Its faculty, alumni, and students have launched 40K+ start-ups since 1940, creating 5.4 million jobs and businesses with over $2.7 Trillion in annual revenues. At the moment we have none of our higher education institutions in this league. Like cillage, this is a deep cultural challenge and needs quick attention along with attention to enriching our rural ecosystem. Thrusts in these two areas should make a huge difference to India's march forward. In the present-day competitive world facing a lot of challenges in terms of very survival of humankind, what H. G. Wells said has become very important. "Civilisation is a race between education and catastrophe". We must ensure that we win this race leveraging quality education for our citizens.

INNOVATION

In the discussion relating to education and sustainable livelihood particularly in India's rural domain, it is clear that this primarily is a cultural issue needing people's participation in transforming themselves into an innovative society based on knowledge and excellence. Similar is the case with taking higher education to a level comparable to the best in the world. Thus, for enhancement of livelihood in rural areas to bridge the urban-rural divide as well as for the country to be in the forefront of technology space, we need large and multidisciplinary conducive eco-systems that promotes high level of excellence and innovation. While the related cultural transformation on a countrywide scale will take time, some efforts to promote innovation eco-systems in specific situations have been very successful. An excellent example of this is BETIC that was envisioned by Prof. Ravi in biomedical product innovation space and has main centres at IIT Bombay, COE Pune and VNIT Nagpur along with activities at several medical and engineering institutions and active participation of several (~1500) clinicians, researchers, students. There is a separate paper by Prof. Ravi in this volume that covers this effort in greater detail. BETIC has emerged as a largest medical device innovation network in the country. In just six years of its existence, BETIC has bagged 16 BIRAC BIG awards and commercialised 21 products through start-ups as well as technology transfers. The effort clearly has been very successful and has provided a lot of learning for development of innovation ecosystems that can be translated to other areas.

ENERGY, AIR, WATER AND WASTE

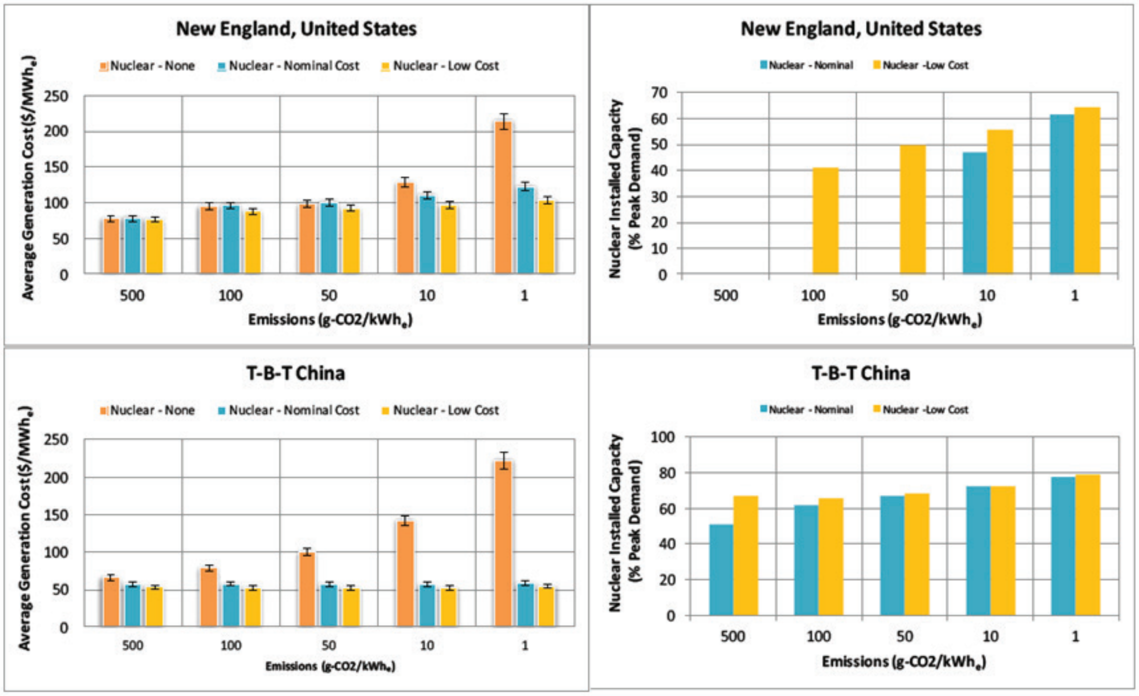
While sustainable livelihoods and education are the most important areas to focus on, there are obviously a large number of other domains that need attention in a large and diverse country like India. Discussing them all would clearly not be possible in this single essay. However, discussing a few of the most important ones would be in order.

Energy, air, water and waste are on the top of my list among them. World is presently fast approaching the tipping point as a result of global warming. Energy production related CO_2 emission being the main driver for this situation while there are other contributors as well. On current trends, as per IPCC, warming will reach the limit of 1.5°C above pre-industrial times between 2030 and 2052. Staying below 1.5°C in the year 2100 will require cuts in GHG emissions of 45 percent below 2010 levels by 2030 and to net zero by 2050. Studies have been done looking at several scenarios for transition to carbon emission free green energy. Aggressive deployment of renewable energy is being pursued the world over. However, the goal of limiting warming to within 1.5 degrees Celsius above the pre-industrial age is unlikely to be realised, in a practical sense, without an enhanced share of nuclear energy, coming into play rather rapidly, in the global energy supply. Comparisons based on levelised cost electricity, which is a measure of the average net present cost of electricity production for a generating plant over its lifetime, does not lead to a fair comparison between renewables and nuclear as there are costs beyond the plant level such as the system costs. MIT report of "The future of nuclear energy in a carbon constrained world" has clearly brought out that "In most regions (of the world), serving projected load in 2050 while simultaneously reducing emissions will require a mix of electrical generation assets that is different from the current system. While a variety of low or zero carbon technologies can be employed in various combinations, our analysis shows the potential contribution nuclear can make as a dispatchable low-carbon technology. Without that contribution, the cost of achieving deep decarbonization targets increases significantly. The least-cost portfolios include an important share for nuclear, the magnitude of which significantly grows as the cost of nuclear drops". A recent report by New Nuclear Watch Institute (NNWI) concludes that "new nuclear build is the most efficient way to achieve decarbonisation of the electricity grid, being able to reduce system carbon intensity by up to 34% per megawatt of installed capacity compared to intermittent renewables". "The falling costs of renewable energy, such as solar PV and wind, do not give governments an accurate picture of how to invest in low-carbon generation", says Michel Berthélemy, a nuclear energy analyst at the OECD Nuclear Energy Agency (NEA). Policymakers must therefore assess the actual costs of decarbonisation and decide a target share of nuclear in a foreseeable future. A look at figure E1 from the MIT report suggests that the share of nuclear around 2050 needs to be around 50% or more.

In India we are well endowed with coal, solar, wind and nuclear (essentially thorium) for significantly meeting our increasing electricity generation requirements in the future. For a large and poor country like India, considerations of energy security and balance of payments would require that we meet our energy needs leveraging sustainable energy resources available within the country. The mix of electricity generation assets from sustainability considerations thus can't go beyond coal, nuclear and renewables. To address the climate change issue, we need to anyway decarbonise as fast as we can. The results of MIT study which covers diverse grid and nuclear capital cost situations would suggest that there is a need to quickly ramp up nuclear generation capacity in the country culminating in ~50% nuclear and ~50% renewable energy as an optimum mix of electricity generation assets. I do hope that the policy discussion in our country becomes comprehensive enough and lead to policy makers giving a push to increasing the nuclear share duly backed up by an aggressive implementation strategy.

Dealing with global warming would actually require a collective global action. Decarbonizing global energy supply would require attention to both, the existing energy systems as well as meeting the rapidly growing energy demand in the emerging economy countries. It is the latter

Figure E.1: (left) Average system cost of electricity (in $/MWh$_e$) and (right) nuclear installed capacity (% of peak demand) in the New England region of the United States and the Tianjin-Beijing-Tangshan (T-B-T) region of China for different carbon constraints (gCO_2/kWh$_e$) and three scenarios of various available technologies in 2050: (a) no nuclear allowed, (b) nuclear is allowed at nominal overnight capital cost ($5,500 per kW$_e$ for New England and $2,800 per kW$_e$ for T-B-T), and (c) nuclear is allowed with improved overnight capital cost ($4,100 per kW$_e$ for New England and $2,100 per kW$_e$ for T-B-T)



Simulations were performed with an MIT system optimization tool called GenX. For a given power market the required inputs include hourly electricity demand, hourly weather patterns, economic costs (capital, operations, and fuel) for all power plants (nuclear, wind and solar with battery storage, fossil with and without carbon capture and storage), and their ramp-up rates. The GenX simulations were used to identify the electrical system generation mix that minimizes average system electricity costs in each of these markets. The cost escalation seen in the no-nuclear scenarios with aggressive carbon constraints is mostly due to the additional build-out and cost of energy storage, which becomes necessary in scenarios that rely exclusively on variable renewable energy technologies. The current world-average carbon intensity of the power sector is about 500 grams of CO_2 equivalent per kilowatt hour (g/kWh$_e$); according to climate change stabilization scenarios developed by the International Energy Agency in 2017, the power-sector carbon intensity targets to limit global average warming to 2°C range from 10 to 25 g/kWh$_e$ by 2050 and less than 2 g/kWh$_e$ by 2060.

that would also help reduce the energy/economic disparities in the world while significantly addressing the climate change concerns. While one does see a beginning of nuclear energy being embraced by new countries such as Bangladesh, Belarus, UAE etc. and there is interest in many more, accelerating this process would require smoothening of some of the barriers to deployment of nuclear energy. Concerns on nuclear proliferation, issues related to spent fuel management and safety concerns are some of these barriers. Use of thorium-low enriched uranium (LEU) based fuel in the time tested 220 MWe PHWRs, which India is in a unique position to supply, offers an excellent opportunity to create an export foot print for Indian PHWRs as well as boost the domestic manufacturing sector while addressing a global challenge.

Energy for transportation which presently is derived primarily from imported fossil hydrocarbons is a matter of serious concern both from the perspective of rising import bill as well as climate change threat. Several initiatives to enhance domestic production of hydrocarbons are being pursued. Also, the Government is giving significant thrust to 2G technologies for leveraging a broader spectrum of biomass for production of bioenergy. Aggressive efforts in this direction can contribute significantly to reduction of energy import bill as well as avoidance of CO_2 emissions.

Clean electricity (nuclear and renewable) and clean bio energy fuelling e-mobility, either directly or through hydrogen fuel cells appear fairly close to practical decarbonisation of the transportation sector. That should be the way forward in my view. I am happy that Government policy thrust in this direction is quite aggressive.

Municipal solid waste issue has reached a crisis point. With several waste dumps around many of our cities rising to be mountains with no additional land, the situation has become a major public health hazard as a result of serious air and water contamination. I believe that a decentralised approach to segregation at source and converting bio-degradable waste to manure and methane with gas picked up by city gas network is an optimum solution to this problem. While this would entail moderate investments, the operations can run in a self-sustainable revenue model. Further the manure getting recycled back to soil to improve soil fertility contributes to sustainable circularity in the agriculture eco-system. This would also lead to significant number of jobs for collection/segregation/recycle, savings in the waste transportation and most importantly the savings in public health expenditure.

Encouraging industry to adopt 3R (reduce, reuse and recycle) strategies moving progressively to circular economy is the key to sustainable clean environment around us. With adequate policy support of the Government, driven by informed public rather than vendors, this clearly is achievable.

Air and water are natural endowments that support life on earth with their own cyclic activity for rejuvenation and clean up. We humans have excessively interfered in them for our selfish gains much to the detriment of ourselves. I think we need to emphasise the following to keep these life support streams healthy;

1. Stabilise population as early as possible through better education, livelihood and awareness.

2. We will need to conceive of our river basins from source to sink as integrated biotic systems, and plan our hydraulic engineering schemes accordingly. Cleaning our rivers and provision of 100% sanitation and sewage management as well as desalination technologies which would reduce the pressure on our freshwater systems should receive priority attention.

3. Reduce GHG emission to preindustrial level by converting processes that lead to their generation to non-GHG emitting processes. In addition, there should be efforts towards CO_2 capture, utilisation and sequestration. All modes of air and water use should return air and water back to the environment well within acceptable quality standards. Other gaseous and liquid effluents should also be controlled to be well within the stipulated emission norms.

NEED TO RELOOK AT THE ECONOMIC MODEL

Some of the vulnerabilities around us also appear to be a result of the way our economic models have been set up. Rather than favouring a more balanced income distribution, these models seem to widen disparities. While degradation of nature is a key concern for our very survival, we do not seem to be adequately compensating for the essential services that nature provides. Without these services like clean air and water, natural cycles to maintain environmental and ecological balance, pollination etc., any activity on earth would be impossible. Similarly, we do not pay adequate attention to compensation of people at the grass roots in key areas like agriculture, public health and rural education that are crucial to elimination of vulnerabilities in our society and economy. Our investments in these domains are also significantly below the accepted bench marks. We need policies where heavy disparities that market forces tend to create, are largely neutralised through recognition of higher national/societal/strategic importance of the contribution of grassroot workers or professionals as well as costs for services that nature provides.

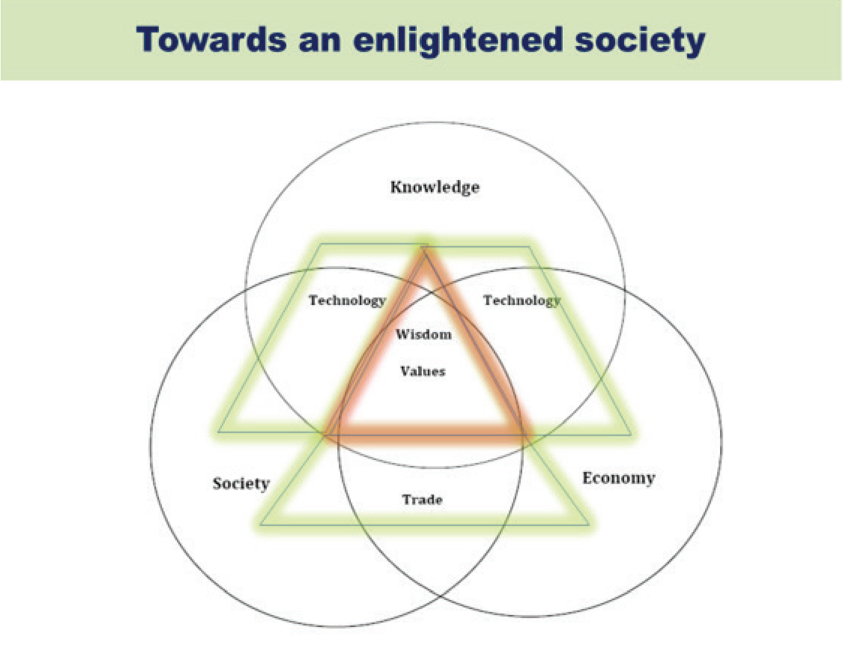
Talking more generally, it seems to me that time has come to think about pricing principles based on true cost of value addition and accepted norms for compensating those who do it. Also, the transactions along the value chain should be restricted to only those who actually add value. Others who are also necessary in this process, should come in as service providers. Leveraging modern technologies and creative business formats, we should be able to develop a healthy and non-exploitative configuration that is fair to all and in particular to the grass root producers and the final consumers.

A balanced approach to land use pattern is another area that needs careful attention. Population density in India is one of the highest among the large countries. We need to arrive at an optimum distribution of land use for habitat and food for humans as well as animals, industry and other economic activities including infrastructure, energy, forest cover and water management. Agriculture, water, energy and environment are heavily intertwined and need to be dealt with, in a holistic manner. Water harvesting, recharge and management systems also need attention particularly in the context of ground water level, irrigated agriculture, flood control and ensuring that rivers and water bodies remain clean and alive sustainably.

CLOSING REMARKS

Clearly, as recognised above there are many other areas as well that need attention. However, given the right human capability building and collaborative innovation culture through Cillage framework, a healthy society empowered at the grass roots, will be able to address them as long as we are able to sustain balance and a level playing field.

In the evolution of any society, there has to be a close linkage with the economy. This is closely linked to the livelihood of people. Knowledge along with the society and economy is the third leg of a three-legged stool. The way our societies have evolved, knowledge has remained on a separate high pedestal, revered by the society but more for an evening spiritual discourse rather than practical engagement on a day to day basis. This has led to the society becoming more transactional since trade occupied a larger part of economic activity. It is very important that there is a much deeper engagement between knowledge and society



as well as between knowledge and economy. That will create (as we are witnessing already) a greater innovation and entrepreneurial activity in the economy leading to new value creation. The joy of doing so would lead to the transactional mind set getting relegated to lower importance. In the circumstances, the moral values in the society should go to a higher order making for a wiser, enlightened and more capable society. Mahatma Gandhi got it right when he said "The difference between what we do and what we are capable of doing would suffice to solve most of the world's problems."

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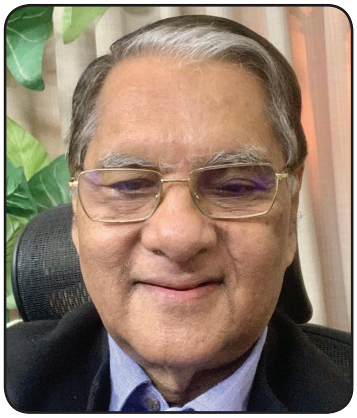

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Author's Profile

Shri R V Shahi is presently the Chairman & Managing Director, Energy Infratech Pvt. Limited, and on Advisory Boards of Indian Energy Exchange; Adani Power; Central Advisory Committee of Central Electricity Regulatory Commission; South Asia Regional Integration, World Bank and other organizations of strategic importance.

Prior to this Shri Shahi was the Secretary to the Government of India, Ministry of Power (2002 - 2007) and under his stewardship the Indian Power Sector went through a major restructuring with the institution of the Electricity Act, 2003 and subsequent National Electricity Policy, 2005 and National Tariff Policy, 2006. Other major initiatives launched include the Accelerated Power Development & Reform Programme (2002), Rural Electrification Policy (2005), Ultra Mega Power Policy (2006) and Merchant Power Policy (2006). Shri Shahi was also directly responsible for the long-term planning and operational performance of the Central Public Sector Undertakings.

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Technology Development and R&D Crucial for Energy Sector

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Energy, Economy, and Development have always remained interlinked since the beginning of civilization. Extent of economic development and, to a great extent, even adequately addressing social needs, is determined by the extent of development of energy and its consumption. India, which constitutes a large portion of global population, has unfortunately been inadequately provided with natural energy resources. The share of India in the world population is 17%, but its share in the global gas, oil, and coal reserves are only 0.6%, 0.4%, and 7% respectively. Obviously, this has resulted in excessive dependence on imports even though energy consumption is rather at a low side, as highlighted in the following Table.

Per Capita Primary Energy Consumption (kgoe)	
USA	6,865
China	2,442
India	670
World	1,839

Coal constitutes a very large proportion of energy basket. This has obviously remained, over decades, an area of concern due to its impact on carbon emission and climate change, in the present form of its consumption.

Share in Energy Basket		
	World	India
Oil	33.1	30.1
Gas	24.2	6.3
Coal	27.0	54.7

Per capita energy consumption in India, according to the National Electricity Policy 2017 (Draft), is categorized by its low level, and a large disparity between urban and rural areas. In 2015 – 16, our per capita energy consumption was 670 kgoe and electricity consumption 1075 kWh per year, which are about one third of world average. The following table would give an idea of per capita consumption of electricity for some of the countries to appreciate how inadequately India is fed or starved.

Electricity Consumption - World Statistics for a few Select Countries

Rank (total)	Country	Total (million kWh/year)	Per Capita (kWh/ year)	Date
1	China	5,564,000	4,038	2016 est.
2	United States of America	3,902,000	12,076	2016 est.
3	India	1,137,000	897*	2016 est.
4	Japan	943,700	7,435	2016 est.
5	Russia	909,600	6,302	2016 est.
6	Germany	536,500	6,519	2016 est.
7	Canada	522,200	14,462	2016 est.
8	Brazil	509,100	2,470	2016 est.
9	Korea (South)	507,600	9,614	2016 est.

10	France	450,800	6,964	2016 est.
11	United Kingdom of Great Britain and Northern Ireland	309,200	4,710	

(*As in the year 2020, it is about 1200)

Another challenging aspect is the proportionately lower position of electricity in the overall energy mix, which is about 17% compared to 23% in OECD countries. The National Energy Policy 2017 (Draft) has rightly recognized that in India a large proportion of energy consumption is in the form of solid and liquid fuels entailing heavy burden on air quality, since electricity at the consumption points is the cleanest form of energy. Domestic potential of different fuels in India has been projected by the NEP till 2040 under two scenarios – business as usual and ambitious target. The following table would indicate that the share of coal in commercial primary energy supply which was 55% in 2015 – 16 is expected to remain between 48 – 54% even in the year 2040 – 54% in case of business as usual and 48% as per optimistic scenario. This means that the climate change concerns would continue to remain a major challenge. Improving the energy consumption mix profile, including the way coal energy is used, keeping in view the climate concerns, will have to be one of the most important agenda for technology development and research in the field of energy. National Energy Policy 2017 (Draft) has projected in the following profile.

Domestic Production

	2012	**2022**		**2040**	
		BAU	**Ambitious**	**BAU**	**Ambitious**
Coal (Mtce)	582	904	1006	1190	1385
Oil (Mtoe)	38	44	46	54	61
Gas (BCM)	48	46	53	95	124

Electricity Capacity

GW	**2012**	**2022**		**2040**	
/		**BAU**	**Ambitious**	**BAU**	**Ambitious**
Gas Power Stations	24	34	39	46	70
Coal power stations	125	266	251	441	330
Carbon Capture Storage (CCS)	0	1	1	26	26
Nuclear power	5	12	12	23	34
Hydro Power Generation	41	61	61	71	92
Solar PV	1	59	59	237	275
Solar CSP	0	4	5	28	48
Onshore Wind	17	62	62	168	181
Offshore Wind	0	2	2	19	29
Distributed Solar PV	0	36	36	102	120
Other Renewable Sources	8	18	20	43	56
Total	221	555	548	1204	1261

Role of Technology Development and R&D, to enable the country to address these challenges cannot be over emphasized. Never before in the past, had India's energy sector experienced such rapidly changing technology scenario as during last ten years. Technological disruption, with emergence of Solar Power has impacted, and is going to impact even more significantly in coming years, entire energy landscape. Another major disruption in automobile sector is already on the horizon, with major consequences on energy. Transport sector including Railways, and Electric Vehicles would create a major challenge to petroleum industry. These developments are positive and highly satisfying for economy and, more importantly, for environment. Indeed these would have been more satisfying if we, as a nation and our scientists and engineers working in India, would have substantially contributed in Solar and EV Technologies. The Integrated Energy Policy (IEP 2006) had listed these and many others including Hydrogen energy, Storage technologies etc. to be taken up through National Technology Missions as has been highlighted in this paper subsequently. For R&D, IEP 2006 has provided a very precise description – "Research and development in the energy sector is crucial to augment our resources, to meet our long term needs, to promote efficiency, to attain energy independence, and to enhance energy security".

The author had an opportunity to address and present a paper on "Frontier Technologies for Sustainable Energy Development: Energy Planning and Policies" in the Plenary Session of 90th India Science Congress held at Bangalore in January 2003. An extract from this comprehensive paper, which was included later in the Author's Book "Towards Powering India" (2007), highlights the range of issues, challenges, and tasks, aimed at the much needed energy development programmes.

Technology Issues

Having given an over view of the perspective covering the next 25 years, it would be essential to have a brief appreciation of technology issues which may be required to be kept in mind. Some of these issues are as follows:

(a) Production and consumption of energy generated through non-conventional sources must be expanded. In this context, each area of non-conventional generation namely Wind, Biomass, Biogas, Solar, Geo-Thermal and Tidal etc. needs to be further researched to make them more and more cost effective. In the field of Wind and Biomass, good progress has been made. There is further scope for upgrading the technology aimed at better utilization, more efficient operation and also at further reduction in capital cost. In the field of Solar, Geo-Thermal and Tidal, we have a long way to go. Solar energy is the eternal source of energy and in India it is available for 8 to 10 months of the year. But, with best of intention, even now the technology is cost prohibitive.

(b) Even in the conventional methods of power generation, there is a need to further improve technology. Super critical and ultra-super critical systems with the objective of substantially increasing the thermo-dynamic efficiency of power generation must be attempted.

(c) Decentralized distribution generation with both conventional and non-conventional technologies with better capital cost economics could emerge and provide a breakthrough in rural electricity supply system.

(d) Indian coal having excess ash content must be subjected to better coal beneficiation technologies. The technology should aim at minimum loss of heat value and maximum yield and at the same time substantial reduction in ash content.

(e) Integrated Gasification Combined Cycle (IGCC) has been under discussion and expectation for a long period of time. Further development of this technology and its adaptation to Indian coal could lead to a breakthrough in making Indian coal more acceptable and environment friendly.

(f) Coal Bed Methane (CBM) technology could prove to be very relevant for Indian energy sector. A beginning has been made.

(g) In the Combined Cycle Power Plant based on gas substantial technological development has yielded, within the last 25 years, significant increase in efficiency, from 48% to almost 60%. The process of continuous upgradation should go on.

(h) Indian Transmission sector has to have larger proportion of extra high voltage, and ultra high voltage transmission system besides a suitable blend of HVDC and AC system. These systems need to be brought in the Indian manufacturing sector.

(i) In the nuclear field, further advancement is necessary. Fast Breeder Reactor and Thorium Based Technology can address the problem of inadequacy of fuel and could provide comforts for large scale expansion of nuclear power capacity.

(j) On the Demand Side Management, there is a considerable scope to replace the present conventional lighting system by CFL in the short-term and LED in the medium term. These technologies must get indigenized and manufacturing must start.

(k) Technologies relevant to environmental protection in terms of their adoption, adaptation and new development pose a real challenge. While we need to pursue our approach that India will have to wait for cost effective new technologies, we cannot totally remain divorced from our obligations to see that climate change related issues are also given the required priority in our policy formulations and programme of actions. A harmonious balance will have to be struck.

A number of organizations are engaged in research and development efforts, in each of the energy fields; there is need for research and technology development. All organizations engaged in this field namely BHEL, NTPC, Central Power Research Institute, Council of Science and Industrial Research, Department of Science and Technology, Indian Institute of Sciences, IITs, Petroleum Research Institute, CMPDI, and others need to network and integrate their efforts. Technology development is needed on the supply side, i.e. on production to make them more energy efficient and cost effective. Technology development is needed on the demand side to make the consumption more energy efficient. Technology development is also needed on all the processes to see that maximum environmental safeguards are achieved.

It has been established beyond doubt that India has a large pool of talents. We have the need and challenges identified long back, but obviously these are dynamic and keep changing. We have to ask ourselves whether we have the right mindset, a determination and a systematic plan of action to seriously and vigorously pursue the charted path. During 2005-06, the author had an opportunity to chair, as Power Secretary, Government of India, the Working Group on Power, for the required preparation for the Eleventh Five Year Plan document. A specific team was set up, besides a few other teams on different issues, to focus on Technology Development and R&D. This Group came out with a comprehensive Approach Paper on this issue, an extract of which is given below:

Technology Development and R&D

The group has emphasized the following:

a) Introduction of larger size energy efficient thermal generation for Indian coal with a good mix of fossil and renewable source of energy.

(b) Efficient operation of a large grid with 800 KV AC and DC transmission with high reliability, flexibility and open access in transmission.

(c) Technology development and demonstration of distributed generation covering biomass, bio diesel, solar, wind and focus on micro grids.

(d) Reduction of distribution system losses, energy conservation methods and introduction of large-scale automation in distribution sector.

The recommendations include the following:

1. Technology advancement and research and development have so far not been properly addressed. Major organizations like NTPC, NHPC, Power Grid, on the generation side and BHEL, ABB, SIEMENS on the manufacturing side must enhance their budget allocations substantially for research and development. The utilities should aim at least about 1% of their profit to be utilized for research and development activities and the manufacturing organizations should consider 3 - 4% to be provided for technology development.
2. Networking of R&D resources and expertise would be an important strategy aimed at getting effective results. CPRI, apart from testing, must reorient its strategy and activities towards research.
3. Ultra Super Critical Boiler Technology, IGCC technology and oxy-fuel technology are well researched abroad but have to be developed for Indian coal. NTPC, the major Indian Central Sector Utility, should have its R&D centre strengthened to expedite the work started during 10th Plan on IGCC. It is recommended that this project may be given top priority and completed with the help of BHEL or with a private party, if necessary.
4. There is a need to work with specialized S&T laboratories under CSIR and other space and nuclear establishments to develop material technology for advanced boilers, fuel cells, solar power, battery and super conducting material application in power sector.
5. For the projects of national interest to be taken upon collaborative research route the estimated R&D expenditure of 452 crores is recommended. It is also recommended that in future, capital fund support for R&D should be reduced and utilities and industries should collaborate to fund R&D projects.
6. An institutional change in handling R&D is required. A suggestion is to have generation, transmission and distribution R&D units to be established as separate entities in the central sector undertakings or to set up a corporate technology centre for R&D activities in various areas of power sector.
7. R&D import should be exempted from custom duty to encourage indigenous R&D.
8. Power sector should seriously consider attracting young talents by offering them challenging opportunities. This will be possible by encouraging R&D and offering a good package, like many MNCs are offering at present.
9. A High Power Committee in R&D should monitor R&D projects and regulate funds. This will avoid duplication and ensure competitive R&D.
10. Organizations like CPRI and NPTI should be spared from manpower optimization rules where vacant positions are surrendered. This is in view of depleting cadre of scientists and specialists in these organizations.

From the above extracts, which convey briefly the essence of the paper presented in the Indian Science Congress in 2003, and the document prepared by the Working Group on Power for Eleventh Five Year Plan, it could be observed that important technical issues have been identified from time to time to address major technological challenges in the energy sector, as highlighted not only in these two documents, but also in the past. However, the seriousness with which many of these needed to be pursued has been perhaps less than what was needed. One of the reasons, which have often been highlighted, is the lack of financial resources needed for major Technology Development and R&D Projects.

The author had an opportunity to be closely associated as a Member on the Committee for formulation of Integrated Energy Policy 2006. It has been recognized in this document that “Energy R&D has not got the resources that it needs. We need to substantially augment the resources and allocate these strategically.” The IEP recommends that “A National Energy Fund (NEF) should be set up to finance Energy R&D ………… In the developed world industry generally spends more than 2% of its turnover on R&D. In India the total expenditure on R&D in 2004-05 was Rs. 610 Crores ………. Even at one tenth of the rate at which industry in developed countries spends on R&D, 0.2% of the turnover of all energy firms, whose turnover exceeds Rs. 100 Crores per year, we end up with Rs. 1,000–1,200 Crores per year which will increase over time. We should be spending much more than this on R&D." The IEP recommended that "Each company in the field of energy should be mandated to spend at least 0.4% of its turnover on R&D. Any contribution made by the company to NEF could qualify for full deduction from the Income Tax."

As a matter of fact, the International Energy Agency, which has studied the National Energy Policy 2017 (Draft), has also made a number of observations with regard to commitment of industry towards R&D. It says "India's energy research, development and demonstration (RD&D) landscape is dominated by the public sector, specifically the Central Government, and involves a broad range of Ministries and related agencies. The role of private sector actors in technology innovation is expected to become increasingly important looking ahead." With regard to public sector funding, the IEA observes "as a percentage of GDP, public spending on all RD&D in India has remained flat over the last two decades. India's gross expenditure on research and development as a percentage of GDP has been flat at approximately 0.69%. This spending level ranks below that of other emerging economies such as China (2.1%), and Brazil (1.3%)……." With reference to the private sector energy RD&D landscape, the IEA observes "However, private actor uptake on RD&D activities remains low in India relative to most countries. The concept of "frugal innovation" – a term applied to Engineers inventions that meet core user requirements without the backing of major corporate RD&D budgets or high level of consumer finance – has found application in the energy sector, including via the use of novel information and communication technologies."

Integrated Energy Policy 2006 articulated in detail and listed a number of specific projects which could be pursued. An extract is given below.

In view of the discussion above the Committee felt the need for several National Technology Development Missions crucial to India's long-term energy security. These technology missions must pull together all current efforts and resources being devoted to the technologies relevant to the mission and place their responsibility as separate but linked parts of a single chain of command working towards specific and time-bound deliverables. The missions must engage industry, academia and India's R&D infrastructure of laboratories and research institutions. The missions identified below exclude nuclear energy as research in that field is progressing well under the various institutions controlled by the department of Atomic Energy and covers fission, fusion, breeding of fissile material, use of Thorium as also a number of non-energy related fields. The following National Technology Missions are recommended:

- **In-situ coal gasification:** Given its vast reserves of relatively poor quality coal, which might prove uneconomical for extraction beyond 300 meter depth using convention technologies, India needs to take the lead in developing this technology in order to enhance the life of its most important and dominant energy resource. This technology would extract energy from deep seated coal without the high ash that accompanies Indian coal.
- **Integrated Gasification Combined Cycle (IGCC):** is a clean coal technology that India has been pursuing for some 3 decades. These efforts should be brought under a mission to establish efficacy with Indian coal and likely commercial viability.
- **Coal to Liquids and/or Gasified Coal to Liquids:** If crude settles at above $45/barrel on a long-term basis, adapting this technology to Indian coal could increase India's energy security. This technology was successfully

deployed in South Africa using South African coal. They have tested Indian coal and confirm that the technology works.

- **Carbon capture and sequestrations:** India's energy mix will remain dominated by coal at least to 2031-32 and possibly beyond. In order to grow in a sustainable manner capturing carbon and sequestering it would become critical for India in the years to come. Such technology has already been deployed commercially in conjunction with enhanced oil recovery from adjacent oil fields in three locations worldwide.

- **Bio-energy mission:** This mission could cover three distinct areas related to bio-energy. These include: (i) Bio-diesel from non-edible oils such as Jatropha and Karanj; (ii) Cellulosic ethanol; and (iii) energy plantations. A bio-fuel mission to plant Jatropha or other appropriate oil plants on 4,00,000 hectares of wasteland within three years has been undertaken to assess yields under alternative agro-climatic and soil conditions, diverse cultivation practices and different levels of inputs such as water and nutrients. The mission will identify germ plasm of promise and develop high yielding varieties. Even if the experiment shows little scope for economic exploitation of bio-diesel, the expenditure could be justified just as a failed oil exploration effort, by the large local employment generated. A similar mission needs to be mounted for energy plantations wherein the biomass generated could be gasified or combusted directly in wood fired boilers for power generation. Funds available under NREGA (National Rural Employment Guarantee Act) could be used for meeting the cost of planting under both these schemes. Production of cellulosic ethanol is getting considerable attention and India should also mount a separate mission for R&D in this emerging energy source.

- **Storage technologies:** Storage technologies are important for using intermittent sources of power and for the automotive sector. Super conducting storage devices and super battery technology should be focused on, given that cost and higher capacity to weight ratios are still big challenges.

- **Solar:** Solar technology is often seen as relevant for niche applications. Given that solar energy is one of our major energy sources and the only renewable energy source with sufficient potential to meet almost all our energy needs, we should give a high priority to development of solar technology for large-scale deployment. A technology mission should be mounted to break barriers to wider use of solar thermal and for bringing down the cost of solar photovoltaic by a factor of five as soon as possible.

- **Advanced materials:** Several technologies depend on developing advanced materials. A mission to support this could actually cut across several technologies and could also draw from current work done in a variety of fields such as nuclear, space, transport, etc. for applications in the field of energy.

- **Hydrogen:** Development of Hydrogen as an energy carrier is being pursued in many countries. Hydrogen can be used to generate electricity in a fuel cell or it can be burnt directly in internal combustion engines. Hydrogen, however, has to be produced by expanding another primary or secondary form of energy. This can be gas, coal, oil, solar energy, biomass, hydro or nuclear energy. It is also possible to produce it through microbial action. A mission covering all aspects of hydrogen production, storage, transport, deployment and use, can be justified on three considerations:

  (i) Since many countries are working on hydrogen, the R&D on applications will find international market.

  (ii) Some of the R&D for fuel cell based vehicles is common for electric vehicles which may become attractive with advancement of battery technology; and

(iii) If economic production of hydrogen through electrolysis of water using solar energy, and/or nuclear energy or from microbial action materialises, and storage, transportation and distribution of hydrogen become economically viable, hydrogen could become a clean and endless energy option.

❖ **Gas hydrates:** A technology mission for assessment and exploitation of gas-hydrates is justified given India's abundant gas hydrate reserves in deep waters."

The National Energy Policy 2017 has reinforced many of the recommendations of the Integrated Energy Policy 2006 and has also made additions keeping in view the emerging technological changes. The Technology - Way Forward and R&D Strategy as outlined in the NEP are given below:

TECHNOLOGY - WAY FORWARD

The way forward in induction of technology is discussed as follows:

An industry-academia alliance is best suited for identifying areas for technology induction. This initiative will be led by BEE in the demand sectors, and by sector-specific energy ministries in supply sectors.

Energy access, exploration/evaluation, production, alternate technologies and energy efficiency will be the main areas of technology focus.

A technology roadmap will be laid out for different energy sub-sectors through the exercise of the alliance as stated above. This will guide the efforts over the medium term especially as results can only be achieved over time.

The Government will supplement private sector efforts in technology development through its dedicated agencies/PSUs in different energy Ministries, and Department of Science and Technology (DST) as well as Department of Bio-Technology.

The Government may place its fund with the technology developers and allow operational freedom by maintaining an arms-length relationship.

Diplomatic Missions abroad will be harnessed in tapping the Indian diaspora in providing guidance to the technology related efforts, especially from reputed technology centres at select locations.

Many technology providers are unwilling to part with technology, but offer partnerships on a variety of terms. In some cases, such procurement may not be amenable through established processes. Our PSUs will make imaginative arrangements to access technologies, and be open to engaging with technology providers on risk-reward basis.

Technology related efforts will be dove-tailed with the Skill India Mission to have a symbiotic relationship between the two.

The energy Ministries require technical advice at top levels which is often missing. Therefore, a position of Chief Technology Officer (CTO) will be created in each energy Ministry for guidance, supervision and technology related initiatives.

R&D STRATEGY

As discussed earlier, technology development and R&D efforts go hand-in-hand. Many of our felt needs may not be a high priority area for the scientific community abroad. The strategy for developing technologies locally through R&D will be as follows:

The Government recognizes its role in supplementing commercial R&D. While technology may have many suitors, it is R&D which struggles due to investment risk. Therefore, Government will enhance its support to energy R&D.

The Ministries will deploy the new mechanism created for technology development herein to identify the areas of R&D pursuit.

A distinction, however, is needed to be made between fundamental research and R&D for applications. India offers a vast potential for research in energy sector deployment.

Many emerging sectors such as clean coal technologies, CCS, hydrogen as a source of energy are been actively pursued abroad. The Ministries will support joining international R&D where it is felt useful.

Policy research has a great relevance in deployment by suggesting practices to make new products/technologies financially viable. Hence, the Government will also support such research in technical centres.

Laboratories operated by CSIR and other scientific ministries will be mainstreamed with related energy Ministries to make their research productive. A linkage will be provided through the newly created position of CTO.

The research facilities operated by energy sector PSUs such as ONGC, NTPC, and CIL hold a vast potential for peer reviewed research. They will be made autonomous for greater independence and accountability on the lines of National Institute of Wind Energy (NIWE) and National Institute of Solar energy (NISE).

Financial incentives/tax reliefs will be offered to encourage energy related research in the private sector.

R&D cannot be incubated overnight. An ecosystem to support it will be created in due course, by forging a closer relationship between the industry and academia. Longer duration joint research projects will be initiated in consortium between government and companies.

As already mentioned earlier, the International Energy Agency, which made a detailed study of the National Energy Policy 2017 (Draft), has made a few specific recommendations in respect of private sector engagement to spur energy RD&D investment and recommendations for the Govt. of India. These are extracted below from their Report.

PRIVATE-SECTOR ENGAGEMENT TO SPUR ENERGY RD&D INVESTMENT

A distinct feature of the Indian innovation system is the dominance of the central government as the country's main RD&D funder. In most countries, the private sector drives RD&D spending and market-led technology innovation activities.

RD&D programming could be optimized to better spur private-sector investment and leadership. Engaging with private stakeholders is key to: a) leverage greater overall investment in technology innovation despite increasingly limited government resources; b) facilitate lab-to-market paths for key emerging technologies and accelerate deployment; and c) optimize the allocation of public funds in those specific innovation areas suffering from financing gaps due to higher risks and capital costs or longer-term returns on investment that are less appealing to private-sector actors.

The effectiveness of existing indirect measures (e.g. RD&D tax incentives) to stimulate broad-based industry innovation activity should be examined, in tandem with the current focus on targeted direct funding programmes. Intellectual property frameworks within energy RD&D programmes should also encourage private-sector participation and collaboration with public bodies and academia.

RECOMMENDATIONS BY IEA

The Government of India should

- Work towards a more strategic approach to energy RD&D; systematically embed RD&D components in broader energy policies; lay out a long-term energy RD&D strategy and technology roadmaps; use impact-oriented results measurement at a broader scale than project level; systematically collect, monitor and make available detailed data on energy RD&D, including but not limited to funding.
- Establish stronger inter-ministerial co-ordination to clarify innovation priorities and consolidate energy RD&D activities, thereby improving the effectiveness of Indian RD&D despite increasingly limited resources.
- Follow through on the government's commitment to double clean energy RD&D funding, and ensure that ongoing funding

levels align with India's rapid growth and national goals for energy access and sustainability.

- Make public energy RD&D programmes more accessible to the private sector and create incentives for private investment in energy innovation, from early R&D to commercialisation in line with Make in India.
- Continue to engage in international collaboration through bilateral and multi-lateral platforms (MI, TCP by IEA and other partnerships) to access available solutions in other countries and disseminate results from Indian energy RD&D.

NUCLEAR POWER

Any discussion on Technology Development and R&D would be incomplete unless we recognize and reflect on initiatives, which have been launched for power sector, by our Nuclear Scientists and Engineers. The initiative on development of Fast Breeder Reactor, aimed at substantial expansion of Nuclear Power capacity, in the wake of relatively short supply of domestic Uranium, is worth mentioning. The Government sanctioned the Pressurized Fast Breeder Reactor Project in September 2003 at an estimated cost of about Rs. 3,500 Crores, with a projected completion period of seven years. As a matter of fact, this is the single most important initiative in the entire energy segment as it addresses the most important challenge of insufficiency of domestic Uranium and yet assures a large scale expansion of Nuclear Power. Obviously, the efforts have seen ups and downs, arising out of various technical difficulties on the one hand, and the systems and procedures of project management including procurement process on the other. In April 2012 the project cost was revised to about Rs. 5,700 Crores. The project is now expected to be completed by December 2021. The Standing Committee of Parliament has commented "Even though it would have taken almost two decades of work on PFBR, when commissioning takes place, this is a pioneering initiative of which India can be justifiably proud of. It will transform our Nuclear Energy Programme."

CONCLUSION

This paper has brought out the supreme need for energy development, its production and consumption, which need to be accelerated, since India is not well placed even in terms of per capita global average consumption of energy, let alone being anywhere near a large number of developed and developing countries. Secondly, potentials of energy resources within the country are far too less compared to the proportion of India's population in the global context. Thirdly, India's energy profile, particularly electricity profile, is highly fossil fuel centric, with larger dependence on coal, thus leading to enormous burden on environment and climate change issues. Given this background, challenges for Technology Development and R&D are enormous. We need to evaluate our responses in the light of what we have done and what have been the outcomes. Power sector, even as per the latest National Energy Policy 2017 (Draft) keeps the role of coal based power generation by the year 2040 at around 50%. As we know, coal has remained stagnant in terms of any new innovation to respond to Clean Coal Technologies over last fifty years, though several options aimed at more environment friendly use of coal in power generation have been talked during this entire period. Power industry – both Generating Group and Manufacturers have equally been not so enthusiastic about how to make radical and strategic shifts in terms of developing and promoting new technologies and processes. Recent Solar initiatives, in the second decade of the 21st Century, in terms of Technology, do not belong to India. We continue to import more than 70% in spite of Government programmes on exponential expansion. A few recent developments, however, through Make in India approach, provide a ray of hope. As regards the third major group of energy viz. Petroleum and Gas, our import dependence has only increased over the years to now more than 85%, and gas production during the last ten years has witnessed either negative growth or stagnancy. Obviously, we need to do a lot more. Inadequacy of financial resources for R&D has been argued in this paper, as articulated by various agencies from time to time, as being one of the reasons for technology development agenda being far behind the expectation and requirement. It has also been argued in this paper that Mission Mode for picking up right technology issues to research and bring it to the stage of successful outcomes, with sufficient financial provision and commitment of our Scientists and Engineers would be the right approach to move on. India has an impressive pool of talents, we need to have the right level of will and determination and appropriate financial support mechanism. Public sector, private sector and government, all have to recognize the need for resources and provide the same.

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Author's Profile

Professor Indranil Manna, Vice Chancellor, Birla Institute of Technology Mesra, is an educationist and materials engineer with research spanning over a wide range His works are highly referred and cited by the research community. Besides BIT Mesra (2020-present) and IIT Kharagpur (1985-present), Professor Manna has taught in Nanyang Technological University, Singapore (2000-01) and IIT Kanpur (2013-17). Earlier, Professor Manna served as the Director of CSIR-CGCRI, Kolkata (2010-12) and IIT Kanpur (2012-17). As an active researcher, he visited Universities abroad like Max Planck Institute at Stuttgart, Technical University of Clausthal and Berlin, University of Ulm, and University of Liverpool as a guest scientist. Prof Manna has a staggering number of widely cited publications to his credit and has supervised 25 PhD theses of impact and had been involved with several sponsored projects IIT-Kharagpur. He is a Fellow of all the national academies of science (INSA, IASc, NASI) and engineering (INAE) in India. He is also a Fellow of The World Academy of Sciences (TWAS) and a Member of the Asia Pacific Academy of Materials (APAM). IIEST, Shibpur in 2015 and IIT Kharagpur in 2016 presented him Distinguished Alumnus Award and Kazi Nazrul University, Asansol and Kalyani University conferred DSc (hc) on him in 2016 and 2017, respectively.

He is a member of the Research Boards of several industry/R&D and chairs several national level selection committees He is a recipient of several awards and honours including National Metallurgist Award (2018), MRSI Distinguished Lecture Prize (2017), TWAS Prize in Engineering Sciences (2013), INAE Visvesvarya Chair Professor (2009-2011), INAE-AICTE Distinguished Industry Chair Professor (2007-2009), Metallurgist of the Year (2003) of the Ministry of Steel, Alexander von Humboldt Fellowship (2001-2002) and DAAD Fellowship (1988-1990) of Germany, INSA Young Scientist (1993), Young Metallurgist (1991) and many more. He is a former President of the Indian Institute of Metals (IIM) and the current Vice President and President-designate of INAE.

New Metals – A Myth or a Reality

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ABSTRACT

From stone age to space age, materials played a very important role in defining the level of advancement of the society. For load bearing or structural applications, the capability of metals to offer multiple benefits of combining strength with utility, fabricability with durability, availability with versatility, and cost with benefits is simply unique and unmatched. Actually metals were literally a gift from the heaven to mankind as meteorites imported metals from the space well before homo sapiens established its supremacy on earth or managed to extract copper from its ore nearly 9000 years ago. The story of evolution of metals, from pure, wrought or cast metals, particularly iron and steel, to the most modern metallic alloys like super alloys and maraging steel is truly a fascinating story. In course of this march of metals over 2000 years, mankind has not only mastered the art of extraction and processing, designing and fabrication, joining and machining, but also learned the nuances between bonding and properties, thermodynamics and kinetics, aggregate and structure, and most importantly, the logic of correlating the properties with microstructure, composition and process parameters. Yet the insatiable urge to improve and create a new metal or material remains unabated. It is now well understood that the new metal with better structural properties will not necessarily be of a new or unknown composition but in all probability be of a new constitution or microstructure that can offer new functionality to surpass the present level and enable newer application. This article presents a lucid discourse on the history of evolution of metals, its structural characteristics, the concept of microstructure, to end on possible strategies of realizing the dream not just once but perpetually to design and develop new metals by microstructural engineering.

ENGINEERING MATERIALS

The history of human civilization is synonymous with the ability and efficiency of harnessing natural and synthetic materials to the benefit of human society. Materials, since the inception of civilization, have played a significant role in shaping the face and level of advancement of the society. This is why the different eras of our ancient civilization are branded as the Stone, Copper or Iron ages. Even in modern times (since onset of industrial revolution in the fifteenth century), various consecutive developments of engineering materials are often linked to the periods of steel, aluminum, semiconductor, plastics, carbon, nanomaterials and biomaterials. There is a reason why the historians as well as the economists find it prudent to brand an era of ancient civilization by the material harnessed from nature, or with the new materials synthesized in a given period. The logic emanates from the fact that a new material, compositionally or structurally, often provides a crucial breakthrough in performance and functionality and enables translation of innovative ideas and design into new components, devices and machines with a much higher level of utility and efficiency. Materials science, engineering and technology has continuously enriched and enabled human society with improved standard of living and security against exigencies. Survival and growth of human civilization has thus always been directly linked to the level of exploitation of materials for developing rudimentary tools or weapons in the pre-historic period to the most sophisticated components, devices, machines and systems in the modern era.

Among all forms of materials, the ones most useful to mankind, for making life enabled, secured and enjoyable are called engineering materials. In simple terms, materials needed for any engineering purpose, naturally occurring or synthesized, to create a device, tool, appliance, structure, amenity or a complete system qualify to be termed as engineering materials. Elements of science and innovation allow exploitation of engineering materials to contrive a new and better solution that does not exist in nature as a readymade solution or realized yet. Water, for example, is not an engineering material because we drink it, but because it is useful to generate energy, derive work, dissolve components and perform various engineering activities. In such simple terms, almost all matter in any physical state can offer some utility and hence qualify as engineering materials. So be it.

Undoubtedly, metals should come to the fore of that list not only for historical legacy but for their sheer volume of applications and applicability. From the oldest metal artefact, a copper awl [1] (a drill or a conical tool) unearthed in Tel Tsaf village of Israel dating more than seven thousand years, all the way to the most wonderful and useful metal of modern era, the super alloys (material for aero-engine turbine blades [2]) that has survived sustained use in the most challenging conditions and has been still evolving since its earliest formulation nearly a century ago, metals are surely one of the most fascinating engineering materials that the human civilization has benefited from. The history of evolution of metals and alloys is therefore engrossing as it reflects one of the finest examples of human urge and perseverance to constantly explore, master, excel and advance through science, engineering and technology.

HISTORY OF METALS

Mankind possibly started using metals for making useful implements over 9000 years ago (5000 to 3000 BC) in the chalcolithic period by melting of copper and experimenting with smelting, which led to discovery of how to get copper from its ore [3]. By 2500 BC they learned the art of granulation of gold and silver and their alloys. The Bronze age began in around 2000 BC when they managed to make a harder alloy, bronze, by alloying tin with copper. About 3000 years ago, by 1500 BC, they discovered and started using iron. From this earliest record to the most recent times, 118 elements have been discovered so far, out of which nearly 95 are metallic. In fact, on 28 November 2016, the International Union of Pure and Applied Chemistry (IUPAC) approved the name and symbols for four most recently discovered elements: Nihonium (Nh), Moscovium (Mc), Tennessine (Ts), and Oganesson (Og) with atomic numbers 113, 115, 117 and 118, respectively. But the most useful metallic solids are based not on the exotic or rare elements, but only on a few widely available, fairly stable and easy to extract and fabricate ones, like iron, aluminum, copper, chromium, nickel, etc.

METALS – CHARACTERISTICS AND UTILITY

But what is a metal and what is not? If one goes by common experience or trait, like hard or soft, high or low melting, light or heavy, the possibilities will be endless and create more confusion. One needs a sound scientific basis that can allow a unique classification. To evolve such a strategy, the only option is to adopt the unique criterion of classification of solids based on bonding characteristics. We know that atoms or molecules are the smallest elementary particles with independent existence that make up the bulk solid and retain all the properties attributed to that aggregate. Bonding is the glue that makes up this solid aggregate and endows all its characteristic properties. The nature of this very bonding can provide the unique and unambiguous criterion to classify pure solids. Accordingly, engineering solids in pure form can be divided into three major groups, namely, Ceramic (with mostly ionic bonding), Polymeric (with predominantly covalent bonding) and Metallic (having characteristic metallic bonding) [4]. The electrons, the cement or glue binding the elementary species of ions, atoms or molecules into a solid aggregate are transferred between the nearest neighbors to lend them specific electrical characters (cations and anions) in ionic solids, shared between a specific pair, or neighbors in covalently bonded chain or complex aggregates, and shared among an entire array of periodically arranged cations in a metallic solid. All characteristics attributed to pure solids evoking typical response called properties due to mechanical, electrical, magnetic, thermal, chemical or any other activation, which we call the properties, can be explained through this simple model of atomic aggregate. Of course, nature, barring a few exceptions like gold or silver, never offers a material as a pure or elemental solid. Most of the materials or metals are stored in the nature for millennia in the form of various complex aggregates called minerals and ores. We extract metals from such mixed compound aggregates through artificial means called extraction of metals and then mix in desired proportion to synthesize a homogeneous solid solution or an alloy (stainless steel), compound (barium titanate), composite (concrete), hybrid (laminates) or simply a heterogeneous mixture (bitumen/asphalt).

Going by the common experience or traits, a solid object which is usually hard, lustrous, drawable or deformable, can be melted and solidified across a critical temperature or range, and possesses good electrical and thermal conductivity, qualifies to be called a metal or metallic material (e.g. copper, gold, silver, iron, titanium and aluminum, and even alloys like steel, brass, bronze and monel). Going strictly by chemistry, a metal is an element while, an alloy is a solid solution (like solidified sugar syrup). But both are commonly referred to as metals or metallic materials. As already mentioned, metals are characterized by metallic bonding which means an aggregate of positive ions located and vibrating in specific positions in a three-dimensional periodic lattice permeated by a cloud of delocalized or free electrons. Metals easily ionize to form positive ions (cations) in an electrolyte and carry low electronegativity. Metals are solids at room temperature maintaining definite shape and volume with the exception of mercury and possibly gallium, which are liquid at room temperature.

Nearly 95 out of the total of 118 elements in the periodic table are metals or having metallic characteristics. However, several elements lie in the border between metals and non-metals and are branded as metalloids, like boron, silicon, germanium, arsenic, antimony, tellurium and polonium. Some elements like hydrogen, though gaseous, may manifest metallic characters under extreme pressures or low temperatures.

Metals are so useful for engineering purpose mainly because of the excellent combination of mechanical properties like strength at room or elevated temperature (under tension, compression, shear or torsion), toughness (in unidirectional or cyclic loading), and modulus (under one/two/three dimensional loading condition). When heated, metals expand uniformly, become more plastic and ultimately melt. On the negative side, metals are heavy, readily suffer corrosion in ambient condition in contact with an electrolyte and oxidize at elevated temperature. Threats of fatigue under cyclic or alternating loading and of creep at elevated temperature are certain limitations that designers must take care of for applications such as bearings and turbines.

METALLIC BONDING

It is better to reiterate at this stage that metals are metals principally due to metallic bonding [4]. All general properties of metals like crystallinity, density, ductility, malleability, hardness, conductivity (thermal and electrical), opacity and luster, sonorous response, and even propensity to degrade by corrosion and oxidation can be explained by this unique bonding among the constituent atoms invoking the concept of free electron or electron gas or electron sea model of metals.

In any multi-electron atom, the force of attraction between the electrons in a given electron orbit and the positively charged nucleus decreases as the radial distance from the nucleus increases due to the shielding or screening effect. The shielding effect can be defined as a reduction in the effective nuclear charge on the electron cloud, due to a difference in the attraction forces on the electrons in the atom. Though the number of electrons in a given shell increases as the distance of the electron shell from the nucleus and its diameter or circumference increases, most metals carry fewer or no electrons in their outermost shells due to which valence electrons in metals are usually decentralized and free to wander around. In contrast, electrons between nearest neighbors are transferred in ionic bonds and shared in covalent bonds. Thus outer shell electrons in metals do not belong to any specific atom but to all the metal atoms around them as if these electrons are a common property to the entire array. As they float free within the entire lattice as if in a sea of electrons, metallic bonding is often explained in terms of electron sea or electron gas model and the attraction between the mobile electrons and periodically arranged cations constitutes the metallic bond.

A metallic solid comprises a three-dimensional array of positively charged cations arranged in a perfectly regular and periodic fashion along all directions and planes, but filled with free electrons acting as a glue and not letting the cations manifest their electrical character individually, even to the nearest neighbor. Thus, all properties of metallic solids are imparted by this unique metallic bonding that distinguishes metals from non-metals characterized by partial or complete covalent or ionic bonding.

PURITY, IMPURITY AND SOLUBILITY

A metal by definition is a pure element, one of the 95 out of 118 elements featuring in the periodic table. However, it is rare to find or even extract a metal which has no impurity in it. In reality, a metal is technically an alloy, a crystalline solid solution containing varying amount of foreign atoms of a different atomic number and size either added intentionally (hence called a solute) or dissolved by default (hence called an impurity) during extraction or processing. Going by size, the solute or impurity atom can either be substitutional or interstitial depending on whether the solvent-solute atomic sizes are comparable (say, within 15%) or significantly smaller, respectively. In the former case, the solute atom simply occupies a vacant lattice site or replaces a solvent atom at the expense of creating some strain (expansion or contraction) and related stress field around the replacement which either must be bigger or smaller than the solvent atom. In case the solute atom is significantly smaller (like typically in case of hydrogen, nitrogen, oxygen or carbon entering into a lattice of iron, copper, etc.), instead of substitution, the foreign atom somehow manages to accommodate itself in the open spaces left between the neighboring atoms as one would expect to see gaps between hard marbles of identical size touching each other only tangentially but not filling up the entire space or volume occupied by them. The resultant two main types of solid solutions or alloys, substitutional and interstitial, considerably differ in terms of several mechanical and functional properties of interest.

Solubility of a given solute in a solvent in the solid state, besides size difference, depends on several other parameters. An empirical set of principles, originally proposed by William Hume-Rothery (1899-1968) at the University of Oxford and hence called the Hume-Rothery rules [5], stipulates that feasibility of alloying or dissolving solute atoms into a lattice of solvent atoms is governed by the difference in size, valence and electronegativity of the concerned atomic pair. To be more precise, these rules predict that alloying is likely if the atomic size difference is within 15%, the solvent is of lower valence than that of the solute if at all they differ in valency, and the elements that make up an alloy should belong to the neighboring groups in the periodic table and not largely differ in electronegativity. Not only metallic, these rules apply to ceramic or ionic solids as well. However, these rules are empirical and exceptions do exist both in metallic and ionic solids or alloys. Moreover, solubility may be unlimited in the liquid or molten state but is rarely unrestricted or complete in the solid state. In fact, solubility is partial or limited in most of the metallic alloys, and usually changes with temperature. The higher the temperature, the larger the lattice parameters and voids in a crystalline solid, and hence the greater the solubility of a solute in a given solvent lattice.

THERMODYNAMICS AND KINETICS OF METALS AND ALLOYS

Stability is an important issue we often face in our daily life. The same is also a major concern in engineering, particularly with regard to reliability or longevity of a structure, device or machine, be it my own house, car or just a cellphone. Material is the heart of any hardware, small or big, besides the intellectual part like design and logic associated with it. When a device malfunctions, the root is often not the design, logic or software involved, but the material used to build the device. It is quite likely that the material degraded over a period of time due to interaction with the environment during use and underwent natural deterioration (aging due to weathering, corrosion or fatigue) or sudden failure (unanticipated development like sudden spike of stress or temperature). Whether it is degradation of the concrete or steel reinforcement in the roof of my house due to rain and weathering, wear and tear of the piston in the engine bore of my car, or leakage in the battery of my cellphone, the fact remains that failure warranting a change is primarily due to the degradation or malfunctioning of some key material over a period of time through natural interaction or unexpected development. No such necessity arose when the same house, car or cellphone was new; but change with time is inevitable.. The question is when will the change happen and why? More importantly, how can we quantify and predict the changes so that deterioration can be arrested and failure can be predicted, if not prevented?

On boiling, water evaporates and on cooling in a refrigerator, it solidifies into ice. Both the changes are caused by the change in temperature. An iron nail or rod left in the open under the sun and rain rusts and loses its utility with time. But the rust never returns to pure iron on its own unless one collects all the scrap, melts them in a furnace and casts and forges them again into a rod or wire or nail. A goldsmith beats a piece of gold into a plate or a wire and bends it to make a beautiful earring out of it in no time but not forgetting to heat it intermittently in between using a Bunsen flame lest the wire turns too brittle and cracks. Why does iron rust spontaneously, why does gold harden on hammering and why does heating in between restores ductility?

The answer lies in the thermodynamic principle and a function called Gibbs or Helmholtz energy, derived from two related thermodynamic functions called enthalpy and entropy. In principle, all these quantities can be derived from a single intrinsic material or chemical property called specific heat, the thermal energy needed to change the temperature of unit mass of any pure substance by one degree centigrade or Kelvin under normal pressure. To make matters simple, thermodynamics allows to monitor or decide only on the basis of relative changes and not by absolute quantity. Thus, Gibbs energy change (ΔG) and not the absolute value of Gibbs energy between the product (final) and reactant (initial) state, say, pure water below and above the freezing temperature, rust (iron oxide or hydroxide) and pure iron at ambient condition, and cold worked (hammered) and annealed (soft) gold can decide whether a change is expected or not.

All changes either involving a change in the physical state (vapor, liquid, solid) or not (within the same state, say solid) are determined by the relative values of ΔG of the concerned material between the final and initial states. This very change must be negative, i.e., the value of ΔG of the final state must be lower than that of the initial or standard state. The implication is profound. Water can vaporize or solidify only if the temperature changes are such that pure water is heated above

100°C or cooled below 0°C. One cannot expect vapor to condense to water while at a temperature above the boiling point, and ice to melt into water unless it is exposed to warmer temperature above the freezing point. Thus, ΔG also determines stability by ruling whether a change may happen or not, under the given condition.

For any such change, a large scale rearrangement of constituent species of the material (atoms, ions, molecules) is necessary and that process of reorganizing into a new entity (like ice from water, rust from iron or softened gold from beaten wire) is called phase transformation, which may involve change of state (solid to liquid or vice versa) or be confined entirely within the same (solid or liquid) state.

Phase transformation of a given phase or phase-aggregate of a known composition in the condensed state can primarily happen due to a change in temperature or pressure. Phase equilibrium or transformation due to simultaneous variation of both temperature and pressure is possible only for a single or unary system (i.e., pure material). For all practical applications, dealing with pure matter, especially in the bulk form for structural application is extremely rare. Phase transformation of an alloy only by pressure in practical applications is also very rare. Thus, it is more common to deal with variation of phases and phase aggregates as a function of temperature for binary, ternary or multi-component systems. For designing an alloy, one needs to predict or read what phase or phase aggregate is stable for a given composition and temperature combination or field, and when should that change if reference conditions are changed. The guide map that can offer such a pictorial representation of information about phase and phase aggregate, phase equilibrium and transformation for a given composition and temperature combination in the entire composition-temperature space of a binary, ternary or multi-component system is called the equilibrium phase diagram. It obviously means that diagram is derived primarily from equilibrium condition or consideration, which requires time or enormous patience to allow the system to reach a steady state at a given temperature. However, pursuing or maintaining equilibrium condition in industrial operation is practically impossible. Yet phase diagrams play a very important role in designing and utilizing an alloy, already established or new. Both thermodynamics and kinetics principles are required to be used to design a new material or process, as the former takes time into consideration, while kinetics dictates the rate of transformation as well as the difficulty of a transformation, or change at local, or global level.

As already mentioned, a phase transformation in the solid state involves definite changes in the structural arrangement of the constituent atoms or molecules or ions, either organized in crystalline (period array) or in non-crystalline (aperiodic aggregate) arrangement. At this point, hence, it is pertinent to dwell briefly on the structure of solids in ideal form and their real existence.

STRUCTURE OF SOLIDS

A solid is a solid because it has a definite shape unless it is deformed or heated. The atoms, molecules or ions that make up the solid experience strong forces of bonding and do not alter their positions unless acted upon by thermal activation or mechanical forces. These tiny particles (< 10^{-10} m) are never at rest unless we cool all the way to absolute zero (0 K). Instead the atoms always vibrate with a definite frequency (10^{13} – 10^{14} Hertz) and amplitude (proportional to temperature) about their mean position of rest at a reference temperature. Yet they arrange themselves in 3-d space to form a solid below their respective melting temperature in either periodic or aperiodic way. For the sake of simplicity, if we assume atoms are non-deformable marbles of same size packed in a box of definite volume, the marble to marble distance can either be identical and repetitive along any given direction, or vary at random. In the former arrangement, each marble will have identical surrounding and any one of them can be considered the starting point to begin the exercise of constructing the entire aggregate marble by marble simply by repeating a marble at the predetermined location or point along three mutually perpendicular directions in three dimension. To make this construction simpler, one may now replace the marbles with points or coordinates where marbles are allowed to be located and call it a point or space lattice. In view of the identity of surroundings, we may further simplify the description by imagining that the entire space can be constructed or filled by a smallest building block just the way the children build a house by placing simple cubes or blocks. Let us call such a building block a unit cell with the condition that a unit cell is an imaginary block composed of atoms, ions or molecules, which retains all the geometric properties of the parent solid, and can actually make up the entire solid when repeated in three directions. Thus, the unit cell is a replica of a crystalline solid. In the simplest form, a unit cell will be a cube of closed volume with identical lengths along edges and angles between the faces. Obviously, not all the crystals possess this simplest description.

Geometrically, one may ascribe six parameters to completely describe or define such a cube or polyhedron. These parameters, actually called the lattice parameters can be the three axial lengths along three mutually perpendicular axes of the Cartesian coordinates and three axial angles among any three faces with common edges. Systematic variation of these lattice parameters, one or more at a time, may define seven such unit cells called cubic, tetragonal, orthorhombic, rhombohedral, hexagonal, monoclinic and triclinic. They are called primitive cells as they assume that marbles or atoms can occupy only the corners of the unit cells. If one allows marbles or atoms to be located also at non-primitive sites like center or face or base of the unit cell, one may design seven more unit cells with the same seven shapes but more effective number of marbles or atoms per unit cell. However, the total possible variation covering both primitive and non-primitive designs now reaches fourteen and they are called the Miller-Bravais crystal lattices. No matter how hard one tries, the total number of crystal lattices with translational symmetry in all three dimension will never exceed this magic number of fourteen. At this time, let us remind ourselves that we assumed marbles of atoms of identical size, considering only pure metals with a unique atomic number. But nature offers us infinite possibilities of variations by choosing any of the 118 elements or 95 metallic elements to create materials, not just a pure one but as solutions or compounds. In that case, the lattices may consider atoms of dissimilar sizes too, and hence crystal lattices may assume fairly different size and, but still be connected to only the fourteen fundamental forms. Actually, nature allows much more freedom than choosing only dissimilar sizes of atoms. It permits even placing or combining multiple atoms or molecules or ions per lattice site making not only the unit cell bigger but much more complex. Thus in reality, through the number of primitive crystal system is only seven and the total number of primitive and non-primitive lattices or unit cells can at best be fourteen, the total number of crystal structures can literally be infinite. In other words, seven crystal systems or fourteen crystal lattices are imaginary and simplistic motif, only to visualize the possible arrangements of species that make up a crystalline solid. Thus, a crystalline solid made up of periodic arrangements of atoms or molecules or ions, in reality, can be much more complex, interesting and varied beyond a finite count.

To err is human. Even nature is no exception. Crystalline solids from its melt or vapor are never totally perfect and instead, contain crystalline defects of zero (point), one (line), two (surface) or three (volume) dimension due to inaccuracies arising and retained during processing, either by man or nature. One could ignore the defects if they were trivial. The reality is that these crystalline defects play such a crucial role in determining the properties of engineering materials that one needs to worry more about the nature and density of defects than the fundamental structure itself in order to ensure the required strength, ductility, diffusivity, conductivity, reactivity and almost all important properties of interest.

Moving ahead, if we tend to believe that all useful solids are crystalline, we are grossly mistaken.

A vast majority of solids could be aperiodic or non-crystalline, in parts or in total, like the polymeric aggregate, silicate or non-silicate glasses, and partially ionic and covalent minerals and ceramic solids. The variety and utility of these non-crystalline solids is enormous and no less important than metals. This commentary on solids in general, though neither complete nor exhaustive, should help one appreciate the possible intricacies of structure of solids and what it means to design and define a new metal or materials.

STRUCTURE OF METALLIC AND INTERMETALLIC ALLOYS

Metals enjoy metallic bonding and are mostly crystalline in nature. Incidentally, more than three-fourth of the pure metals belong to one of the close packed structural variants of either face centered cubic (FCC) or hexagonal close packed (HCP) structures with the highest (74 %) packing density in their respective unit cells. Out of the remaining, nearly two-third possesses body centered cubic (BCC) structure. The exceptions are a few, e.g. bismuth (rhombohedral), tin (diamond cubic), indium (body centered tetragonal), etc. besides of course those which are molten at room temperature like mercury, cesium, francium and gallium. Many metals change their crystal structure from one form to another with change in temperature and/or pressure due to the properties of allotropism (reversible) or polymorphism (irreversible). Usually the more close-packed structure (FCC or HCP) is more stable at room temperature than at high temperature, e.g. titanium, zirconium, cobalt, beryllium, sodium, etc. A very prominent exception to this rule is pure iron which solidifies from melt as a BCC metal, converts to FCC at 1401°C but again transforms to BCC at 912°C and remains so until room temperature. Most of the useful properties of iron including magnetism, solubility and wide variation of strength is related to such allotropism.

Most metals are ductile yet strong having both high yield and ultimate tensile strength. Metals are not only endowed with well-defined slip systems, i.e., combination of co-planar close packing directions (along which atoms touch each other) and planes (having higher planar density of atoms), but also carry one-dimensional line defects called dislocations that allow permanent or plastic deformation at a stress level at least one-thousandth of the theoretical shear strength of the metal required to move or slide one atomic plane over the other In other words, deformation of metals does not require shearing of the entire atomic plane on the neighboring plane above or below it. Instead, permanent deformation can be effected through localized sliding or gliding of the line defect from one end of the crystal or crystallite to the other end by cooperative exchange of atoms across the line defect leading to advancing of the slipped part by one atomic distance compared to the unaffected region. Strength of a metal can thus simply be explained by whether dislocations cannot or can easily slip or glide under the resolved shear component of the applied load or stress on the slip system. Non-crystalline solids do not possess dislocations. Ionic or covalent solids, even if they carry dislocations, cannot utilize the presence of these defects the same way as in metallic crystals simply because of polarity or different nature of bonding among the neighboring atoms or ions in these non-metallic systems. Thus, both unique bonding characteristics and crystalline structure of metals prove beneficial to make them both ductile and strong at the same time.

Most metals can easily dissolve another metal in it and form a substitutional solid solution and maintain the same crystal structure as that of the larger component or solvent. At times, two metals, a metal and a metalloid (carbon, boron, silicon, selenium), or a metal and a non-metal (nitrogen, phosphorus, sulfur, hydrogen) can form a solid solution or a compound having a completely different crystal structure and physical (density, melting point) and mechanical properties than either of the principal components (solvent or solute). These alloys or compounds may form when the constituents vary widely in terms of atomic sizes, valence and electro negativity (Hume-Rothery rules). The resultant new classes of solids manifest properties between metallic and non-metallic solids and hence are called intermetallic phases or compounds depending on whether they show a solubility range or not (fixed stoichiometry), respectively. The latter variety is usually lighter, stronger but brittle, possesses complex crystal structure, melts at higher melting point and is more stable than metals. They are particularly useful for structural applications at high temperature where performance of metals is a suspect. The intermetallic alloys can be of various kinds, namely, electron compound (having specific electron to atom ratio), Laves phases (fixed solvent to solute atom ratio), interstitial or size compound (having widely different sizes of solvent and solute atoms) with fixed or variable stoichiometry, etc. Intermetallic compounds can be an independent entity, a pure solid phase or compound. In addition, intermetallic phases and compounds can evolve out of a metallic matrix as a precipitate due to change in solubility or other thermodynamic conditions with change in temperature. This precipitation can lead to development of interesting composites of ultra-hard phases dispersed in a ductile metallic matrix. The classic examples of exploiting such a possibility is found in age hardenable aluminum alloys, maraging steel and even super alloys. On the other hand, monolithic intermetallic phases and compounds do offer an interesting alternative to metals for various new and high specific strength applications, particularly at elevated temperature, which is not yet fully explored.

STRENGTHENING MECHANISM

Strength is the primary criterion for design, development and selection of materials for structural or load bearing applications either in static or dynamic conditions. However, it is not a unique property; its definition and requirement can widely vary depending on the nature (static, dynamic, cyclic or alternating), direction or type (tension, compression, torsion, shear) and condition (temperature, strain rate) of loading. Technically, strength of metals can be described in terms of relative difficulty or ease of movement or gliding of dislocation on the slip plane by the resolved shear component of the applied load This resistance to dislocation movement can arise from multiple sources and circumstances. The most effective strategies for resisting easy gliding of dislocation or plastic deformation can be through:

- solid solutions strengthening (due to stress field around a bigger or smaller solute atom),
- grain refinement (due to barrier to dislocation movement from larger specific grain boundary area),
- phase transformation (due to change in crystal structure)
- precipitation hardening or coherency strengthening (due to formation of uniformly distributed precipitates that are coherent with the matrix),
- dispersion hardening (due to physical barrier posed by foreign, insoluble and incoherent particles),
- strain hardening (due to cold deformation and increase in dislocation density),
- supplementary methods like crystallographic texture, composite aggregate, etc.

A new alloy for structural application will have to utilize one or more of these strategies depending on the alloy composition, solubility, service condition, prior history, dimension of components, etc.

THE MARCH OF METALS

We discussed the physics of metals at length covering bonding, structure, properties, followed by the means of strengthening. The aim is to examine the scope of developing a new metal or metallic alloy better than what is available now. Better in terms of strength, fabricability, reliability, and any other criterion that may emerge for a specific application. From the Neolithic period of stone age (8000 to 3000 BC) to the current space exploration age through the Bronze age (3000 to 1200 BC) and Iron age (500 to 300 BC, even 43 AD), the principal aim was to find stronger material useful for multiple applications like hunting, safety and protection, mostly for structural applications.

Despite the novelty and promise of various new materials of extraordinary properties and prospect, steel in multiple variants of the main genre is the only material that has continued to rule the field of structural or load bearing application for the longest period in human history, since the earliest evidence of production in or around 1800 BC in Anatolia, a part of the present Turkey. Starting from the earliest invention until almost the 15th century, steel was mostly a precious and expensive material used for making swords, weapons, artillery and for military purpose.

By 3rd century AD, China developed the art of mass production of high-quality steel using an approach bearing similarity with the Bessemer process, which was later developed and popularized in Europe in the 19th century. It is believed that steel making know-how percolated to Japan from China. The Egyptians knew the technique of heating and quenching the steel to make it hard and then reheating to an intermediate temperature to bargain toughness at the expense of some hardness to make better swords and knives even in 900 BC. But mass production of steel in modern times received a fillip only after Henry Bessemer (1813–1898), an English entrepreneur, was successful in removing excess carbon from pig iron by blowing oxygen into the melt. Excess carbon, as in cast iron, makes the alloy harder but too brittle to work or use. Removal of carbon from less than 2 wt.% changes the phase aggregate to make it stronger and tougher and at the same time, more amenable to deformation and fabrication. Since then, successive improvisation and invention of various steel production processes like blister steel production, crucible steel melting, Bessemer steel making, open hearth process, oxygen blown steel making, electric (resistive, arc or induction) steel making and ladle steel making technologies have evolved to make better, cheaper and more useful grades of steel. These developments were mostly to produce plain carbon steel where the properties primarily depended on the amount of dissolved carbon (0.1 to 1.0 wt. % carbon) with various types of post-processing heat treatments to vary its strength and other mechanical properties.

The magic of alloying to make enormous progress in widening the spectrum of properties and utilities of steel came subsequently. The most spectacular advancement in that direction emerged through invention of stainless steel in1912 that revolutionized the scope and utility of an already versatile engineering material widely used in consumer goods, infrastructure, transportation, ships, manufacturing and military in the modern world. Despite temporary slump or decline due to economic recession (as the stock market crash in 1929), production of steel steadily increased decade after decade, spread from continent to continent and eventually turned to be a yardstick of economic growth in the twentieth century.

The versatility of steel is further enhanced by its ability to form newer compositions to meet the emerging challenges of technological innovation by tailoring the composition and microstructure. No wonder that this alloy of carbon in iron remains the second most widely used material for structural application even today, only second to concrete. As already stated, the uniqueness viz. namely, allotropy, electronic exchange interaction and solubility of carbon, the principal alloying element in its interstitial voids. From plain carbon steel to alloy steel, stainless steel and tool steel, the evolution of steel spans over more than a few centuries. Steel was synonymous with the growth and prosperity of a nation, so much so, that even in recent years, the economic advancement of a nation is often judged by the quantity of its annual steel production.

Incidentally, total production of steel in the whole world only forty years ago was less than 500 million tons (Mt), 716.4 Mt in 1980 (forty years ago), which took another 30 years to double (1413.6 Mt in 2010) and stood at 1869.9 Mt in 2019 [6]. More than half (53.3 %) of that global figure is produced by China alone (996.3 Mt), that too primarily by one single Corporate (Baowu Group, 97.47 mt), which is slightly lower than the total annual production steel in India last year (111.2 Mt in 2019). In comparison, iron in the form of wrought iron, cast iron or pig iron was produced in the ancient times by a few men in small pots or pits dug in the earth in batches of a few kilograms over a few days. The modern integrated steel plants in China, Korea, Brazil and even in India produce 10-40 Mt of crude steel in each per year. India aims to reach 300 Mt of crude steel production by 2030.

But why is production of steel considered so important? The answer is obviously related to the unmatched mechanical properties of steel encompassing not just its tensile strength but as a package of hardness, toughness, tensile and compressive strength, deformability, fabricability, weldabilty, durability, recyclability - to name a few. Despite decades and centuries of studious efforts of innovation, there is no substitute for steel in the infrastructure sector, for making buildings, bridges, roads, railways, cities and all that is essential parts of human habitat today.

The prospect of making steel more useful took a dramatic turn through the utility of adding alloying elements to iron by melting and adjusting the composition to make the steel superior in terms of its properties. Gradually, it was learned that compositional adjustment can improve hardenability (ability to convert austenite to martensite in thicker sections), resistance to corrosion and oxidation (e.g. austenitic or ferritic stainless steel), hard or soft magnetic, and retain strength even at elevated temperatures. Alloying can be in small quantity (interstitial free, micro-alloyed, high strength low alloy steel), in medium amount (dual phase, bearing, low or medium alloy steel), or in fairly large and varied extent (stainless steel, tool steel, high speed tool steel). As a result, new components (nut, bolt, pin, tube, rod, sheet), furniture (chair, table, bed), utensils (plate, glass, bowls, knives), building items (door, window, roof, pipe, tap, grill), devices (motor, watch, transformer, oven, furnace), defense gadgets (gun, cannon, missile, bullet), miniature to large machines, power generation and transmission, automobiles, trucks and buses, carriages, railroads, ships, wagons – the list can simply be endless: no single material has served the society better than steel.

MICROSTRUCTURAL ENGINEERING

At this point, it is important to realize that composition is one of the possible approaches to improve properties of steel or for any metallic alloy, but certainly not the only one. Alloying is usually done in the molten state of metals. Besides the cost and efforts of melting, alloying elements can be expensive, adjusting the right composition may not be easy, solubility in the solid state may be limited or nil, and most importantly, the entire strategy can be empirical with no surety of the desired outcome. Hence, a more convenient and effective means of tailoring the properties of metals is by changing the microstructure or microstructural engineering. But what is microstructure?

We talked about bonding (metallic or ionic or covalent), structure (crystalline or non-crystalline), phase and phase aggregate, principle of stability and transformation of phases, and strengthening strategies in solids. We realized that solid metals are mostly crystalline and made up of tiny little entities (0.1 to 100 μm in diameter or width) called grains, all crystalline, interconnected through interfaces or boundaries and differing either in orientation alone (having the same composition and crystal structure) or in terms of both composition and/or crystal structure. The properties, in bulk or microscopic scale, largely depend on the way these grains are packed together within the metal and behave under external stimulus like load, heat, vibration, magnetic or electrical field. For a given composition, this internal arrangement principally depends on the process parameters. The same metal can therefore be rendered soft or hard, ductile or brittle, ferro or paramagnetic, more deformable, permeable or conducting in one direction than the other by intelligent designing of processing strategy in terms of temperature and rate of heating or cooling, extent or rate of deformation or strain, using certain external field (like magnetic, thermal), etc. All these processing strategies can greatly alter the identity, size, shape, morphology, structure, distribution and amount of the grains or phases that make up the bulk solid. Microstructure is thus the composite knowledge embodying all these details.

CONCLUDING REMARKS

The success of design, development and performance of metallic solids for structural applications depends principally on our effective understanding of the correlation among their microstructure, composition, properties and process parameters. For a material of a given composition, properties largely depend on the microstructure, a composite concept comprising information related to (i) bonding characteristics and origin/type of atomic aggregate (crystalline / amorphous), (ii) identity, shape, size, morphology, orientation, and distribution of the constituent phases, (iii) prior fabrication history, and (iv) influence of environment or external stimuli (mechanical or thermal). Both stable (equilibrium) or metastable microstructure in solids evolve through large scale rearrangement of atoms, called phase transformation, during various stages of synthesis or processing and is chiefly controlled by thermodynamic and kinetic parameters. This philosophy and approach based on phase transformation has always been practiced for and applicable to all classes of engineering materials, particularly to metallic alloys. Microstructural engineering is the key to vary the properties of interest over a wide range in the most effective and economical way. Hence, while developing a new material or alloy is always welcome, the strategy must rely more on tailoring the microstructure of an alloy than aiming to create altogether a new solid with entirely new composition.

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Author's Profile

Dr Mangu Singh joined Indian Railway Service of Engineers in March, 1983 serving the organization in various capacities for close to fourteen years. Thereafter, he joined DMRC at the inception stage in November 1997 and contributed greatly in the project implementation of Metro in Delhi and Kolkata and has been responsible for bringing revolutionary changes in the execution of large Metro engineering projects and is considered the foremost tunneling expert and is also the President of the Tunneling Association of India (TAI).

He has introduced new technologies and innovative methods of construction of Metro tunnels and structures to achieve economy, safety, quality and speed of construction. The credit for using Shield Tunnel Boring Machines and introducing New Austrian Tunneling Method (NATM) for the first time in the country goes to Dr. Singh. In addition, he has successfully headed the Clean Development Mechanism (CDM) projects of Delhi Metro, the only such successful project in the Railway Transportation sector in the world. He has been instrumental in preparing the Master Plan and Detailed Project Reports for various Metro system in major cities of the country. His experience includes Rail based transportation projects, its planning & execution, procurement of works and services for Mega Projects on Design and Build Contracts basis, handling multilateral funding agencies, development of bid documents for Metro Projects on PPP basis, management of Concession contracts and CDM projects.

He has published/presented many technical papers in National and International Journals/ Conferences etc and recipient of many prestigious awards. He is Fellow, Indian National Academy of Engineering and Fellow, The Institution of Engineers (India), Member of Policy Board of UITP and also Member of many Institutions.

Challenges of Metro Rail in Urban Transport

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INTRODUCTION

Rapid urbanisation in India has created a variety of infrastructure related challenges for the country's urban planners. Providing quality accommodation, health facilities, education as well as mobility options have emerged as the main concerns as our cities have shown unprecedented expansion and growth in the last few decades. Increasing levels of pollution is another major issue which requires immediate redressal. In such a scenario, development of sustainable and non-polluting transportation options are being seen as an important step which can reduce the impact of vehicular pollution and can also significantly control the congestion on the streets.

In tune with the rest of the world, Metro railway systems are seen as a viable transportation option in India as well, as they can not only transport a large number of people from one point to another but can also do so without polluting the environment. While Kolkata was the first city in the country to have a Metro rail system back in 1984, it was only in 2002, that the country's next Metro network became operational in Delhi. The success of the Delhi Metro subsequently sparked a Metro revolution across the country and today, Metro systems are operational in 13 cities with about 700 kilometres of corridors.

However, a number of challenges have been encountered by the Metro rail corporations while developing these Metro systems. India's cities suffer from perennial infrastructure related problems such as inadequate and congested road networks, unauthorised and crowded residential as well as commercial areas dotted with dilapidated buildings etc. It is a massive challenge for the engineers to plan Metro systems in such areas. In this paper we shall try to analyse the many challenges that Metro systems face in India's urban centres both in terms of construction as well as operation of services.

URBANISATION IN INDIA

According to the World Bank data, the rate of urbanisation in India stood at about 34 percent in 2019. While in the year 2000, it was 27 percent; in 1980 it was only 23 percent. The above data clearly elucidates that the rate of urbanisation has been rather rapid in the country. Especially, ever since the liberalisation of the economy in the early 90s, the rate of urbanisation has further accelerated. Lured by greater opportunities in the urban areas, more and more people are migrating to the cities in search of greener pastures.

As a result, our urban centres are already bursting at the seams. All major cities of the country now have many satellite cities around them as both residential as well as commercial development is now crossing the boundaries of these cities and spilling into the nearby areas. If Gurugram, NOIDA and Faridabad have developed around Delhi, Thane, Navi Mumbai and Panvel have grown up around Mumbai. Bengaluru and Hyderabad have emerged as metropolitan cities in the last two decades and many other tier 2 cities of the country such as Ahmedabad, Pune, Jaipur, Lucknow, etc have shown tremendous growth and expansion both in terms of population as well as the economy.

As per a study by the Delhi based research institute, The Energy and Research Institute (TERI), India's urban population is expected to grow from 410 million in 2014 to 814 million by 2050. India is projected to add four new megacities by 2030. By 2025, 46 percent of Indians will live in cities with more than one million people. By 2030, the number of cities with populations of more than one million will grow from 42 to 68.

Comfortable as well as eco friendly transportation systems are extremely important for any urban centre to develop. Easily accessible transportation solutions act as catalysts for economic development as they facilitate the convenient transportation of a large number of people from one location to another. As a result, residential as well as commercial localities can develop even in the outskirts of the cities and the central areas are spared from further congestion and population pressure.

While most Indian cities have expanded exponentially in the recent times, they continue to face challenges such as rampant congestion on the streets due to continuous increase in population and inadequate road infrastructure. A study by the Boston Consulting Group in 2018 assessed that the Indian cities of Delhi, Mumbai, Kolkata and Bengaluru could be losing up to 22 billion dollars a year due to congestion on the streets. On average, travellers in Delhi, Mumbai, Bengaluru, and Kolkata spend 1.5 hours more on their daily commutes than their counterparts in the other Asian cities during peak traffic times.

In fact, peak-hour congestion, which implies the additional time taken during peak traffic to travel a given distance, in these four Indian cities is estimated at 149 percent, much higher than the Asian average of 67 percent.

METRO RAIL SYSTEMS AS A SOLUTION

In order to mitigate the challenges mentioned above, Metro rail systems are being considered a viable alternative as they are capable of transporting a large number of people without causing any pollution to the environment or further congesting the roads. Metro railway systems are generally designed to operate on elevated viaducts or underground tunnels. As a result they do not obstruct vehicular traffic on the roads and avoid creating further congestion. Metro rail systems also are absolutely non-polluting and do not rely on the fossil fuels for their operations.

Experiences across the world have shown that Metro systems have helped in significantly reducing vehicular traffic on the streets as a large number of people who owned personal vehicles have also preferred the Metro over their own vehicles for their transportation requirements. The environmental benefits of the Metro systems are also acknowledged across the world. Delhi Metro's own experiences in terms of reducing vehicular congestion in India's National Capital Region (NCR) as well its contributions towards the preservation of the environment will be discussed subsequently in this article. Given its immense benefits, about 180 cities in over 60 countries across the world have operational Metro systems today.

THE DELHI METRO EXPERIENCE

The city of Delhi has experienced phenomenal growth in population in the last few decades. Its population has increased from a mere 1.47 million in 1951 to over 20 million now. The number of vehicles has also spiralled from about half a million in 1991 to more than seven million in 2011. To control the ever increasing numbers of private vehicles and provide a sustainable mass transportation option to the people, the planning for a Metro system started as early as 1969-70, when the Central Road Research Institute mooted a proposal of a mass rapid transit system for the city. After more than two decades of deliberations at various levels, the Delhi Metro Rail Corporation (DMRC) was registered as a company in 1995.

One of the landmark highlights of DMRC's composition was that it was a company with 50:50 shares of the Government of India as well as the Government of the National Capital Territory of Delhi. Therefore, the full powers vest with the Board of Directors. DMRC started with the bold realisation that the best technologies available in this sector worldwide had to be incorporated in the system while taking adequate care of the environment.

In the last 25 years since the establishment of DMRC, the organisation has gradually moved from strength to strength. The construction work for the first phase comprising 65 kilometres of lines started in 1998. The first section of the Delhi Metro between Shahdara and Tis Hazari (8.4 kilometres) opened on 25th December, 2002. Backed by impeccable project management and time bound execution, the entire first phase was completed in 2005, a good two years and nine months ahead of schedule.

The next phase of expansion of 125 kilometres was even more challenging. The entire work had to be completed well in time before the commencement of the Commonwealth Games in October, 2010, which Delhi was going to host. In addition, the corridors were also going to reach the NCR cities of NOIDA, Ghaziabad and Gurugram for the first time. However, DMRC overcame the stiff target with great competence and the entire work was completed in little over four years.

With these two phases, DMRC established itself as a symbol of a modern and progressive India which was capable of executing such mammoth infrastructure projects within time and budgetary constraints. However, when the next phase of expansion was finalised, the quantum of work turned out to be equivalent to the work executed in both phases one and two. DMRC was now mandated to construct about 190 kilometres of new sections (including the NOIDA – Greater NOIDA corridor) within about half the time that was available for the construction of Phases one and two.

Delhi Metro overcame this challenge as well with impeccable proficiency and all the corridors were thrown open for operations by the year 2019. Despite carrying out such massive construction all across the NCR, DMRC maintained a superb safety record which was a significant improvement over Phase 2 when some unfortunate accidents had taken place at the Delhi Metro construction sites.

Building a Metro rail service involves the physical challenge of working at different depths and heights. In a city where a simple life safety gear like a driving helmet for a two wheeler is still considered by many to be something that has been forced upon, it is not surprising that it took round the clock surveillance to ensure that safety norms were followed at every point in course of the construction. DMRC ensured minimal traffic disruption to the public by planning efficient traffic diversions and barricading. DMRC coordinated with the civic bodies on a 24x7 basis to regulate and restore traffic, water supply, electricity and communication lines affected by the construction activities. Community Interaction programmes were organised by the corporation's Corporate Communication department to establish an interactive relationship with the local public, who were going to be the future commuter base.

On the Operations and Maintenance front as well, very high standards of efficiency were ensured right from the first day of operations. Any train that is delayed by more than 59 seconds is considered late in order to maintain high standards of punctuality. Despite such stringent standards, DMRC continues to maintain a daily punctuality rate of over 99.9 percent even today when the total network length is nearing the 400 kilometre mark. Hygiene and cleanliness also have been accorded high priority and the sparkling clean trains and stations have actually brought a behavioural change in the citizens who also now participate in keeping the system neat and clean.

Over the years, DMRC's core strength has been its work culture. DMRC's management has nurtured the three pillars of strength from day one, namely knowledge, integrity and punctuality. Undoubtedly, the most energetic driving force at DMRC has been the new sense of confidence instilled by a work culture that has flowed like an elixir from the top to the bottom of the organisational pyramid. Development and nurturing of the work force has been given great importance as a state of the art Metro Rail Academy has been set up to train the recruits at various levels of the hierarchy.

METRO REVOLUTION ACROSS THE COUNTRY

The phenomenal success of the Delhi Metro has today sparked a Metro revolution across the country. For a long time, it was believed that executing a complicated infrastructure project like the Metro in India's congested cities was extremely difficult. However, the Delhi Metro changed that perception. Rather than focusing on the impediments that could come in planning and executing such projects, now the urban planners could see the many benefits that the Metro offered.

Aided by Government policies that supported the development of Metro systems in cities with populations of more than a million, today a total of 13 cities across the country have operational Metro networks. Apart from the major Metropolitan cities, tier 2 cities such as Jaipur, Lucknow, Nagpur, Ahmedabad and Kochi also have developed Metro systems. Patna has also recently started the construction of a Metro network.

Buoyed by the Delhi Metro experience, the authorities are also recognising the fact that Metro networks must be extensive and cover all corners of the city. Developing only one line or corridor may not reap many benefits. Therefore, Mumbai is now constructing multiple corridors parallelly.

Many other cities are also planning their own Metro systems now. Delhi Metro's success has also inspired cities of the neighbouring countries such as Dhaka in Bangladesh to develop their own Metro system. Delhi Metro is guiding all these Metro projects including the one in Dhaka in the capacity of a consultant. For many projects such as Greater NOIDA, Kochi and Jaipur, DMRC has worked as the construction agency as well. It is engaged in a similar role for multiple corridors in Mumbai as well as in Patna.

METRO RAIL CONSTRUCTION IN INDIA'S URBAN CENTRES

Over the years, India's urban centres have grappled with a number of infrastructure related challenges. Because of the continuous flow of migrants from the rural to the urban areas, our cities have always faced the problems of inadequate infrastructure and congestion. Therefore, the construction of Metro systems in the cities has always been fraught with a number of challenges and obstacles. In fact, till the Delhi Metro successfully surmounted these challenges to expand its network in record time, it was widely believed that it would be almost impossible to construct Metro networks extensively in India's cities.

One of the primary challenges that Metro engineers have always faced in India's cities is unplanned development. In the western world, Metro or subway systems are often planned before the settlement of population there. Even otherwise, most of the cities are so sparsely populated with vast open spaces that it is not very difficult to plan Metro systems there. However, In India, we face exactly the reverse situation almost in every city.

For example, in Delhi when we started the construction of the Metro below the old city, we were very apprehensive about the condition of the buildings above as some of them were centuries old. In addition, there were heritage structures of great historical importance such as the Jama Masjid, Red Fort etc, near which our alignment passed. On one side, all the regulations in place for the preservation of the heritage monuments had to be followed, on the other we had to continuously monitor the condition of the other buildings in the area to ensure that there was no harm caused to them. We regularly communicated with the locals and gained their confidence. Round the clock monitoring of the buildings was done with very elaborate instrumentation.

In Kolkata's Bow Bazaar, a few houses had collapsed and some more developed cracks in 2019 during Metro tunnelling work. This caused a delay in the progress of work and led to great inconvenience among the local people. This actually shows how difficult it is to carry out construction work in our cities.

In addition to unplanned residential as well as commercial areas, India's cities also have very limited road space which leaves little space for Metro rail developers to manoeuvre their alignments. Worldwide, most Metro alignments move through road medians or along the arterial roads. However, congested roads in India make it very difficult to plan the alignments along road networks.

In Delhi, a majority of our corridors have been constructed along the arterial roads as in the national capital, the road network is comparatively vast. However, due to severe vehicular pressure, construction of the Metro on road medians or service roads has been very challenging. On each occasion, we have had to study the traffic patterns in great details and come up with suitable diversions wherever necessary. Deployment of traffic marshals with adequate number of signage has been a hallmark of our site management on busy roads.

Ensuring the safety of the site personnel as well as the civilians in the vicinity also is a major challenge in the congested areas. Therefore, DMRC follows an extremely elaborate safety manual while carrying out construction. Right from 1998, when DMRC started construction work, it implemented very strict safety guidelines. Absolutely nobody irrespective of hierarchy is ever allowed inside the site without proper protective equipments. All sites are properly barricaded and adequate signage is installed to let civilians know that construction work is in progress.

For the movement of cranes and other heavy machinery also, elaborate SOPs have been put in place. Whenever, a contractor is taken on board, an orientation session is organised to sensitise them about DMRC's safety requirements. After every phase of construction also, the same is revised taking into account the changes required. Despite being involved in construction work almost continuously since 1998 in the Delhi NCR area, there have been very few accidents involving civilians in and around DMRC's sites. In fact, DMRC's overall safety record has been impeccable and there has been a continuous effort to improve further.

Metro construction is an extremely labour intensive exercise because of the sheer quantum of work involved. In Delhi Metro's Phase 3, about 30,000 to 40,000 workers were involved when the construction work was at its peak. However, in the cities the work force is migratory as they generally come from the rural areas from across the country. Since the work depends to an extent on migratory labour, there are times, when a shortfall is experienced.

During the Covid-19 pandemic, when the construction work was resumed after a nationwide lockdown, a severe shortage of workforce was initially experienced as a large number of migratory workforces decided to return to their native towns and cities. This shortfall was experienced by construction agencies across the country.

In our already congested cities, land acquisition also remains a continuous challenge. Over the years, the land acquisition laws have undergone a number of changes as a result of which it has become extremely difficult for Metro rail corporations to acquire private land. While we try our level best to plan our alignments through public land only, there are instances when the acquisition of private land becomes inevitable. During the Phase 3 construction, we directly engaged with a number of private land owners to amicably settle land issues.

However, Delhi Metro's experience shows that these challenges are not impossible to tackle. With efficient project management backed by impeccable planning and subsequent execution, such challenges can also be overcome. Right from the beginning, a number of important management decisions have been taken to develop a unique work culture. Delays owing to red tapism and unnecessary paper work are avoided and important decisions are taken during the Heads of Department meetings held every week. Frequent site visits are planned and minute issues are tackled right there on the ground.

OPERATIONS AND MAINTENANCE OF METRO SYSTEMS

Over the years, the Delhi Metro has firmly established itself as the mass transportation backbone of the entire National Capital Region (NCR). Prior to the onslaught of the Covid-19 pandemic which led to the suspension of the Metro services in March 2020 followed by resumption with restrictions in September, about 60 lakh journeys were being performed on the Delhi Metro on each week day.

As per a study conducted to analyse the benefits of the Delhi Metro, it could be found that about four lakh vehicles were being taken off from the roads of the national capital every day because of the Delhi Metro as people were preferring to avail the Metro instead of their personal vehicles. These figures clearly establish that the Delhi Metro has been the most preferred mode of public transport for lakhs of people in the NCR.

Right since 2002, when the first section of the Delhi Metro was operationalised, a lot of focus has been given to operate the system in a professional and efficient manner. As mentioned earlier, if any train is delayed by more than 59 seconds, it is considered late in the records. Today, when the Metro system is operating on a network of 389 kilometres with 250 stations (including the NOIDA – Greater NOIDA Metro corridor) making more than 5,000 trips with over 350 train sets, a punctuality rate of over 99.9 percent is still being ensured.

Operating the Metro on such a large scale for over 18 hours every day with frequencies of up to two minutes during the peak hours requires extreme precision and meticulous coordination. Three Operations Control Centres (OCCs) monitor the services round the clock and the maintenance staffs available at stations as well as the 14 depots ensure that the entire system is in complete readiness to operate the services with absolute efficiency.

Manpower management is extremely important to ensure smooth operations on such a large scale. The Operations and Maintenance wing has over 12,000 employees who are supported in their activities by another 7,000 housekeeping staff. In addition, a sizeable team of Central Industrial Security Force (CISF) personnels are deputed to provide security to the system. This huge workforce, divided as per specific skill sets and hierarchies need to coordinate among themselves on a daily basis. They are all like different cogs of a wheel. Even if one of them malfunctions, the entire system is affected.

LAST MILE CONNECTIVITY AND MULTI-MODEL INTEGRATION

The operation of such a massive transit system in a crowded urban setting has another major challenge. It is the issue of providing last mile connectivity to the passengers. Often, it has been observed that while the Metro transports a passenger from one location to another, the passenger finds it difficult to commute to the last mile in a comfortable manner. DMRC has always paid a lot of attention to this challenge. To mitigate the last mile connectivity issues, feeder bus services were started by DMRC in 2007. However, operating these services has been a great challenge for us we primarily specialise in building and operating Metro systems.

In addition, the Delhi Metro today offers a number of other last mile connectivity options. A number of our stations have cycle stands. Recently, some battery run bike operators are providing last mile options from some of our stations. Our stations in the Dwarka sub city, Gurugram, NOIDA, Ghaziabad and Faridabad have GPS enabled e-rickshaw facilities as well. Over a hundred stations on the network also have parking facilities so that the commuters can use their personal vehicles to commute to and from the stations. DMRC has also tied up with cab aggregators Ola and Uber to provide last mile options to the passengers.

To further improve its last mile services, a subsidiary company named Delhi Metro Last Mile Services Limited has been set up. This company is also working towards coming up with new projects to improve the overall travelling experience of the passengers.

An associated challenge has been the issue of multi modal integration (MMI) of different modes of travel. In order to ensure smooth mobility of people, all the modes of travel must complement each other. In our Phase 3 stations, a lot of thought was put towards providing MMI provisions wherever possible. Provision of MMI facilities entail that the station entry/ exit points must be designed in the vicinity of the city bus stands nearby. There should be drop off and pick up bays for non motorised transport options such as e-rickshaws.

Right now also, DMRC is developing 60 more stations with MMI facilities. Our MMI facilities at the Chattarpur station have been highly appreciated where apart from the multi modal integration facilities, we have also provided for landscaped areas, walkways, sitting areas etc.

To ensure better coordination among the different modes of transport operating in an urban centre, many cities across the world have experimented with centralised authorities to operate the different modes of city based transport. For example, Transport For London is an integrated authority which operates all the major modes of public transport in the British capital. However, in none of the Indian cities such an arrangement exists. As a result, sometimes, the different modes of transport plan their expansions in isolation.

No two modes of travel should compete with each other for the same passenger base. Rather, they should complement each other so that the passengers get a seamless experience. DMRC's smart cards can now be used for ticketing in the city's buses. A lot of work has also been done to start a common mobility card using which, passengers will be able to travel on different modes of transport across the country. More such initiatives will have to be started to ensure the integration of all modes of travel in the real sense.

A very important aspect is financial viability and sustainability of such capital intensive Metro projects. As Metro Rail Companies are heavily relying on internal and external borrowings, there is always a pressure to have financial viability. In this regards, Fare Box revenue coming out of Ticket Sales is not enough to meet the O&M cost. Also social conditions in our country do not allow fare to be very high since that has direct repercussion of passenger numbers. Accordingly, more and more innovative ways to generate Non-fare Box revenues have been taken by DMRC which includes revenues from Advertisements, Leasing of Spaces, Leasing of Towers/Cables for mobile service providers etc. which has made DMRC as one of the few Metros in the world that are making operational profit from Day '1' of operations. Such challenges shall continue be mitigated with effective stations planning and support from local bodies for carrying out Property Development.

CHOICE OF TECHNOLOGY AS PER CITY REQUIREMENTS

For any technology dependent infrastructure to develop, it is very important for the planners to decide on the right kind of technologies which can adjust with the conditions prevalent on the ground. When the Delhi Metro was being conceived, a lot of thought was put towards deciding on what technologies we would adopt to take the project forward.

For example, a very strong argument was made for designing the system in broad gauge so that it could be integrated with the Indian Railways system, if needed. However, the Delhi Metro argued that most Metro systems worldwide were operating on standard gauge and therefore, the best technologies in the sector were easily available in standard gauge. Adoption of a standard gauge system could cut costs and expedite the commencement of operations as all components including the rolling stock would be more easily available. As a result, even though the first phase of the Delhi Metro was broad gauge, subsequently many standard gauge corridors were added.

At the very outset of the project, DMRC recognised that the technology needed to build a world class Metro was not available readily with the country then, and therefore, it needed to be procured from outside. However, the decision was clear that the best available technologies which were suitable for implementation in Delhi were to be incorporated. As a result, the Delhi Metro has taken all the advantages of being a late entrant to the sector and has one of the most advanced Metros in the world.

Even as the Delhi Metro procured its technologies from outside, it continued to promote indigenisation through contract conditions which promoted the use of India made products and services. Global vendors were encouraged to tie up with Indian vendors and manufacture their products here. As a result today, many rolling stock manufacturers of global repute have establishments in India. They are also manufacturing trains for other cities in other countries.

DMRC has also made very good progress towards the development of its own indigenous Communication Based Train Control (CBTC) based signalling system. A state of the art lab has already been established and work is in progress.

This apart after every phase, DMRC has analysed its technologies and designs to assess how we can improve further keeping in mind the conditions on the ground. For example, our station designs have become progressively leaner without compromising on passenger amenities since the availability of land for station construction is often limited. In Phase 4, our stations are going to be even leaner than the last phase. These measures are important from the perspective of carrying out construction in the Indian cities which always have the paucity of space.

HANDLING THE MENACE OF POLLUTION

In the urban sector, another major challenge that we face is pollution. In Delhi and its peripheral areas, the menace of pollution attains monstrous proportions in the autumn and winter months. For the last few years, our work has been stopped intermittently during these months as part of a graded action plan of the regulatory authorities to combat pollution. Therefore, it becomes extremely important to implement very stringent pollution control norms at the sites.

In DMRC's sites, we ensure that norms such as wheel washing facility for site vehicles, water sprinkling arrangements to control dust pollution, covering of all construction materials, proper disposal or recycling of construction waste are stringently followed. While the Metro system in itself is non-polluting and has tremendous environmental benefits, we must also ensure that the construction process does not generate any pollution. For each tree cut in the Delhi Metro system, 10 trees are planted. In addition we also try for transplantation of trees wherever feasible.

Since Phase 3, all stations of the Delhi Metro have been designed as green buildings to ensure that they adhere to all environmental norms. In fact, DMRC has tied up with the Indian Green Building Council (IGBC) to devise a rating mechanism specifically for Metro station buildings. All of DMRC's Phase 3 stations have been rated as 'platinum' for adherence to green building norms.

CONCLUSION

In conclusion, we may say that while Metro construction and operation in the Indian urban scenario involves a number of challenges, Metro systems are still the answer to a lot of the modern day mobility hassles in our cities. As mentioned earlier, Metro systems are absolutely non-polluting and are capable of carrying a large number of people from one part of a city to another without causing any traffic disruption.

According to a study to quantify the benefits of Delhi Metro, there was a reduction of over 6 lakh tons of pollutants because of the Delhi Metro in 2018. Similarly, there was a reduction in consumption of fuel up to almost three lakh tons because of our services during the same year. The findings have been enumerated in greater details below:

QUANTIFIED BENEFITS OF DELHI METRO

Descriptors	2007	2011	2016	2018
No. of vehicles off the road daily	16,895	1,17,249	3,90,971	4,19,937
Annual reduction in fuel consumption (tons)	24,691	1,06,493	2,76,000	2,99,000
Annual reduction in pollutants (tons)	31,520	1,79,613	5,77,148	6,19,907
Savings in time per trip (minutes)	31	28	31.76	31.97
Annual reduction in fatal accidents (No.)	21	111	125	135
Annual reduction in all accidents (No.)	93	591	937	1013

As we gradually transition towards a much more urbanised India, with many new cities coming up in the days ahead, we must plan for rail based solutions well in advance to tackle the issues pertaining to intra city mobility. Metro systems, in the form developed so far in the Indian cities are cost intensive and suitable for urban centres with large populations. However, for the slightly smaller centres, solutions such as the Metrolite can be thought of which would require much lesser capital investment and would be suitable for smaller populations. In Delhi also, we are planning two Metrolite corridors in areas where the traffic is not expected to be very high.

Considering the vital importance of Metro rail development for easing the urban traffic problems, it is imperative that it is provided with greater independence rather than being encumbered by the norms, practices and controls of the conventional railway systems. This would help in accelerating the pace of development in this sector.

While there may be many challenges involved in its construction and operation, Metro systems are today a vital component of India's urban transport infrastructure. In the days ahead, many more cities in the country will have Metro systems. This will help in easing the congestion on the roads and in reducing pollution as well.

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Author's Profile

Dr Marlene Kanga was President of World Federation of Engineering Organizations (WFEO) for the session 2017-2019. Dr Kanga has been involved with WFEO since 2007. During her term as WFEO President she brought together members, engineering organizations and member states at UNESCO in a collaborative effort to successfully declared 4th March, the founding Day of WFEO, as World Engineering Day.

She is a chemical engineer and was the National President of Engineers Australia in 2013 and is the Engineers Australia 2018 Professional Engineer of the Year. Her strategic vision on the essential role of engineers in advancing the UN Sustainable Development Goals was first stated in the WFEO Engineering 2030 Plan in November 2017 and the WFEO UNESCO Paris Declaration, March 2018.

Dr Kanga is a board member of the large organizations in Australia including Sydney Water Corporation, AirServices Australia, Standards Australia and other boards involving innovation. She is a director of iOmniscient Pty. Ltd. which has developed artificial intelligence for video technologies.

Dr Kanga is an Honorary Fellow of the Institution of Engineers Australia, Honorary Fellow of the Institution of Chemical Engineers (UK), a Fellow of the Academy of Technology Science and Engineering (Australia), a Foreign Fellow of the ASEAN Academy of Engineering and Technology. She has been listed among the 100 engineers making a contribution to Australia in the last 100 years as part of Engineers Australia Centenary celebrations on 2019, among the Top 100 Women of Influence and the Top 100 Engineers in Australia and is a Member of the Order of Australia, a national honour, in recognition of her leadership of the engineering profession.

Engineering for Sustainable Development in India

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ABSTRACT

Engineers have been changing the world for centuries, developing practical solutions using scientific principles that have transformed our economies and societies. Engineers have been integral to the development of India through the Industrial Revolution, and the development of manufacturing and information and communications technologies. The Institution of Engineers (India) has had a key, recognised role over the past 100 years in driving nation building through engineering. As we are on the threshold of the Fourth Industrial Revolution, engineers are needed more than ever before to address pressing problems for sustainable development in India and internationally. In India, access to clean water and sanitation and reliable energy as well as the development of sustainable and resilient cities, efficient transport and resource management, are key challenges to be addressed. The UN Sustainable Development Goals represent an integrated approach to development. The World Federation of Engineering Organisations (WFEO) has recognised the important role of engineers and engineering in advancing these Goals. Its partners and national members, including The Institution of Engineers (India), have a key role in projects on hand. Engineers in India are already playing their part in developing advanced technologies that are accessible to all and advancing every one of the UN Sustainable Goals through engineering.

Keywords *:* Engineering, Sustainable development, World Federation of Engineering Organisations.

INTRODUCTION

Engineers and engineering have been changing the world for thousands of years. The word engineer itself comes from the Latin Ingenium which is also the root of ingenuity and which means innate quality and especially mental power. Engineers have been recognised for millennia as being the clever people who produce solutions to everyday problems using science, mathematics and ingenuity to do what has never been done before.

HISTORICAL CONTRIBUTIONS OF ENGINEERS

The early civil engineers in India built urban settlements with gridded streets, grand buildings and public baths in ancient times at Mohenjo-Daro in the Indus valley. The Mauryan Emperor Ashoka built the city of Pataliputra in the 3rd century BC, the largest city in the world at that time, controlling an empire that covered most of India. This was made possible by engineers in those early times who not only constructed buildings but water supply and drainage systems and roads that facilitated communication over long distances. The Mughal Emperor Akbar, also used engineering skills to build the planned city of Fatehpur Sikri around 1569, as a new capital to control his vast empire.

The Romans used engineering to extend their vast empires with roads and aqueducts that enabled armies, to travel long distances not only for conquest but also for the fastest possible means of communications. Information and speed of communication was critical, even in ancient times. Many of the cities of Europe from Rome to London owe their early development to these early engineers and we can see some of their magnificent engineering work even today.

The speed with which engineers re-shaped the world gathered pace with the First Industrial Revolution in the 18th century in Europe which was driven by inventions like the steam engine by the great Scottish engineer James Watt and others. Steam engines led to the development of rail networks led by the thinking of engineers like George Stephenson and other discoveries such as electricity and magnetism led to further innovation and inventions that became the core of the Industrial Revolution.

The Industrial Revolution had an impact in the British colonies, including India. Civil and railway engineers created the railway networks that are the foundation of mass transportation in modern India, resulting in the development of cities and ports around the country. For example, eminent Indian engineers such as Sir M Visvesvaraya, built dams and irrigation systems and Mr A C Wadia, brought gas lighting to Mumbai and used steam and electricity for industrial applications, contributed to economic and social development in India.

A desire to improve the quality and quantity of manufactured products resulted in a review by the Indian Industrial Commission, chaired by Sir Thomas Holland. The Commission recommended that a professional institution of engineers be established to ensure the advancement of technology and to uphold the quality of products in various stages of production. The inauguration and first Annual General meeting of the Institution in 1921, was attended by the then Viceroy and Governor General of India, indicating the importance and high prestige of engineers and engineering.

The Royal Charter, granted to The Institution of Engineers (India) in 1935, entrusted the Institution with the responsibility of promoting the general advancement of engineering. The history of the Institution demonstrates the importance of engineering to the nation with the opening of the head office in Kolkata by His Excellency, the President of India Dr Zakir Hossain in 1968. The first Indian Engineering Congress, held at Calcutta in 1987, was inaugurated by the then honourable Prime Minister of India, Shri Rajiv Gandhi. The continued presence of the leaders of India at important Institution events are a testament of the recognition of the importance of engineering and its role in defence and in the development of the economy and society. The current goal of "the advancement of engineering for nation building" also recognises the important role of the Institution and the engineering profession in nation building in India [1].

ENGINEERING IN THE 20TH CENTURY

The Institution has grown and prospered in line with the growth in the importance of engineering and the pace of innovation in the past 100 years in India and internationally. Industrialisation and rail travel have eventually led to the development of jet engines and global travel, and the first computers eventually enabled global connections and access to vast amounts of information. All this was possible through scientific discovery and the practical implementation by technologies by engineers. The creativity of engineers changed the world, affecting the quality of life of everyone in most parts of the globe.

Engineers continue to be at the forefront of shaping our world in the 21st century, economically, socially and politically. In the last 30 years alone we have seen the rapid rise of computers and communication technology. The invention of the smartphone and social media has provided extraordinary access to information and communications to ordinary people. Young people cannot imagine life without a smartphone. Technology has also driven social and political change, now playing a key role in elections, engaging young people like never before – a development that would not have been possible without the extraordinary accessibility of mobile telecommunications [2].

Technology has also provided economic opportunities. Mobile payments systems have expanded rapidly in India especially in response to contactless payments in the COVID-19 situation and is expected to exceed $300 billion by Dec 2020. This enables millions to complete financial transactions via a smartphone, even those without a bank account [3].

The use of identity card systems such as the Aardhar card in India has also enabled other forms of transactions such as access to education and health services. Data analytics and artificial intelligence from large sources of data are enabling the development of policy responses and services for health and education [4].

High speed Wi-Fi, has enabled communications in the remotest parts of the world bringing social and economic change [5]. Engineering has also enabled the exploration of space, including the launch of space rockets, space transportation and human spaceflight from India and perhaps the colonisation of new worlds in the not too distant future. Yes, engineers are transforming our world at an unprecedented pace in ways we could never have imagined even a decade ago [6].

The significant positive effects of engineering are visible in terms of output, productivity and growth, and the innovation capacity of economies [7]. Engineers play a key role in supporting the growth and development of essential infrastructure such as roads, railways bridges, dams, communications, waste management, water supply and sanitation, and energy and digital infrastructure which facilitate communications. They enable a country's economy to grow and develop, which in turn can lead to better economic and social outcomes including improved life expectancy, higher literacy rates and better quality of life [8].

Countries around the world now realize that engineering, science and technology are the route to economic growth, and that it is not possible to have a modern economy without engineering. The major trends that are impacting the world today: COVID-19 responses and the rise of telecommunications for mobile work and education, rapid urbanization and the development of smart cities, climate change and technological innovations and the rise of entrepreneurship, are driving recognition of the important link between a country's engineering capacity and its economic development [9].

Engineers and engineering innovation have been at the forefront of actions to manage the impacts and spread of the COVID-19 virus and the use of innovative technologies to detect, monitor and prevent the spread of the coronavirus. Sensors and artificial intelligence are being used to check temperatures for people entering important facilities as fever is an important indicator of the virus. Sensors are monitoring sewage to monitor the spread of the virus in urban areas. Artificial intelligence is being used for rapid analysis of the performance of possible new vaccines and therapeutic approaches. 3-D manufacturing is being used to produce face shields and other personal protective equipment as well as ventilators and medical equipment that is in high demand. Mobile communications are being used to track and trace people who could be carrying the virus. Importantly, communications have also facilitated on-line learning for millions of young people around the world and for people working from home as lockdowns were implemented around the world [10].

We now stand at the brink of the Fourth Industrial Revolution and the potential creation and mass use of computer systems that will change engineering itself and the way we work as engineers. It is estimated that 90% of the work of civil engineers is embedded in the excellent codes and standards that underpin much of civil engineering. These can be used to build automated systems that may take over routine design work and tasks that once took many months of effort will be processed by a computer in a matter of hours. Building Information Modelling (BIM), simulation, optimisation, geo-spatial, mapping and automation are transforming civil engineering and artificial intelligence will be used for many tasks with little human intervention. This example demonstrates the imperative to transform engineering education and professional development to meet the demands of the future [1].

ENGINEERING CHALLENGES IN THE 21ST CENTURY

With rapid technological advances, engineers are needed more than ever before, for tasks which cannot be easily automated, finding creative solutions to problems and being innovative, especially when resources are limited, using sustainability principles in design, construction and manufacture, managing risk, ensuring safety protecting the environment and eliminating bribery and corruption. Many of these involve value based judgments that hopefully will not be replaced any time soon. We need to be smarter and more ingenious than ever before.

Moreover, we need more engineers with the right skills to meet the pressing challenges of today and tomorrow, in India and around the world. We need the best people to become engineers, because we, as engineers, have a great deal of unfinished business.

Despite the engineering advances of the 20th century, the benefits of engineering have not reached everywhere. About one-sixth of the world's population lacks clean water and electricity in their homes. In India, approximately 99 million lack access to clean water and open defecation, continues to be a critical issue that is contributing to water-borne illness, stunting, and death [12], [13]. These are basic amenities that are essential for the quality of life. We need action on climate change that is already impacting on parts of India. We need to develop liveable cities to address the growth in urban populations and sustainable solutions for housing and transportation.

Cities are transforming India's landscape like never before. According to the UN, around 70% of the world's population will live in cities by 2050. By 2025, Delhi is expected to reach a population exceeding 25 million, Mumbai will have a population exceeding 33 million, 13 cities in India will be larger than 4 million people and 68 cities will have populations exceeding 1 million [14]. The problems of urbanisation, including transport, air quality, food security, water supply and sanitation, energy and communications will all need engineering solutions. Engineers are needed to develop innovative solutions to use energy and water more efficiently, create renewable energy sources and reduce greenhouse gas emissions. Where India is exposed to natural disasters and rising sea levels, engineers are needed for resilient solutions to mitigate these risks.

Having grown up in India, I know firsthand of the rapid pace of change that is occurring, much of it the result of the ingenuity and hard work of engineers. My father, an electrical and mechanical engineer, led projects that brought electricity to many parts of the west coast of India and vital infrastructure to secure India's borders in the Rann of Kutch and in Ladakh in the Himalayas. In the same period, my father-in-law, a civil engineer, developed and optimised the water supply networks in Mumbai and later was Chief Executive of the authority that designed and built four new cities in India including Navi Mumbai, which has a population approaching 2 million [15]. I struggle to find my way around Mumbai, a city I once knew well, due to the phenomenal growth that has occurred.

My ancestral home in Goa, some 400 years old, is also facing rapid change as a result of technology and engineering. It received electricity supply in the late 1960s and the first connection to a public water supply was made less than 10 years ago, in 2011. There is still no public sanitation system. Nevertheless, with smart technology the village is a global player with satellite connections and mobile phones. I have seen our land line telephone number grow from just two digits in the 1970s to 8 digits. However, this growth has been overtaken by the growth in the mobile phone network. There are now more than 1,161 million mobile telephone subscribers in India compared to approximately 22 million land line subscribers [16]. Mobile telephone subscriptions have expanded rapidly and importantly the price is very affordable, connecting most people far beyond the boundaries of their villages. This has had profound implications for the economy, and the quality of life, enabling new businesses opportunities and contribution to the economy even from the most remote villages.

At the same time, young people in these villages have become avid consumers of all things technological and aspire to be engineers. They all have mobile phones and watch the, multiple channels on “ZEE” TV. Large numbers recognise the power of science and engineering. Its pleasing that many want to become engineers. For example, Techfest, organised by the Indian Institute of Technology Bombay, attracts more than 150,000 delegates each year, the largest such event for engineering for young people that is held around the world. I am proud to have spoken at Techfest in December 2017, as an alumna of that illustrious institution and was inundated with questions about engineering as a career choice and its impact on our future [17].

ENGINEERING AND THE UNITED NATIONS SUSTAINABLE DEVELOPMENT GOALS

The enthusiasm for engineering as a career among the young people of India is heartening as engineering is essential for our future and for sustainable development. In 2015, the member States came together at the United Nations, to agree on a new approach to tackling the world’s problems by declaring their commitment to the 17 United Nations Sustainable Development Goals. This represents an integrated approach to development that provides for better outcomes for people, for our planet, and for prosperity, to be achieved through partnership for lasting peace. This commitment recognised that although progress had been made through the Millennium Development Goals, the Sendai Framework for natural disaster risk management and the Kyoto Protocol for mitigating the impacts of climate change, much more needs to be done.

The United Nations has recognised the importance of science and engineering as a key enabler for advancing sustainable development. The UN Global Sustainable Development Report, released by the UN Secretary General in September 2019, concludes that science and engineering is one of four important levers to advance sustainable development [18].

The UN Department of Economic and Social Affairs has also recognised the importance of Science, Technology and Innovation with “STI Roadmaps” to demonstrate how countries can advance with effective policies and governance [19].

The UN Expert Committee on Global Geospatial Information Management, has identified the “geospatial information digital divide” as being an important barrier that needs to be addressed to advance digital economies and sustainable development [20].

The World Federation of Engineering Organisations, of which The Institution of Engineers (India) is a national member, is committed to advancing the UN Sustainable Development Goals through engineering. **Table 1**, Engineering a Sustainable Future in India, shows the work of engineers in India who are advancing every one of the sustainable development goals through engineering innovation and new technologies.

Engineers are needed to address global challenges that have no boundaries such as developing efficient and cost effective renewable energy solutions, providing safe access to water and sanitation, improving health outcomes, developing smart and sustainable cities and resilient infrastructure, taking action against climate change, protecting the earth’s resources and our oceans and considering the reuse and recycling of precious resources. The WFEO UNESCO Paris Declaration on the commitment to advance the UN Sustainable Development Goals through engineering was signed by me on as President of WFEO and UNESCO, at the 50^{th} anniversary celebrations of the organisation in Paris in March 2018. [21].

The World Federation of Engineering Organizations Engineering 2030 Plan commits to advance the UN Sustainable Development Goals through its committees, working groups and partners. The Plan will continue until 2030, reporting annually on progress [22].

Projects that have been or are to be developed by WFEO and its international partners include:

- Review of the current international engineering education benchmarks for graduate attributes and professional competencies in partnership between UNESCO, WFEO and the International Engineering Alliance (IEA) to ensure that they meet the requirements of employers for today and the future, and incorporate the values and principles of sustainable development, diversity and inclusion, and ethical engineering practice. This transformative project is progressing well with consultations in progress with members and partners and a schedule for adoption by June 2021. I am proud to be leading this initiative for WFEO [23].
- Improve the standards of engineering education within national engineering systems, including the training of engineering educators, and thereby extend the reach of multilateral recognition of engineering education and professional development of engineers through mentoring and support initiatives that are supported by institutions that have already achieved international standards. These institutions are the national members of WFEO and are being supported in Africa, Asia and South America. I am proud that the National Board of Accreditation India and The Institution of Engineers (India) are key partners with WFEO, IEA and UNESCO in this project [22 op.cit].
- Facilitate professional lifelong training to support engineers throughout their careers in partnership with key employers of engineers such as the International Federation of Consulting Engineers (FIDIC) for which the national members of WFEO will provide the delivery mechanism. The Institution of Engineers (India) will have an important role through its training facilities in India [22 op cit].
- Increase the participation of women and girls in engineering through programmes that attract girls to science and mathematics and to consider careers in engineering, and promote changes to curricula and professional development requirements that will support the retention of women in engineering. WFEO members and UNESCO are key partners in this important activity [24, 25].
- Support the activities of UNESCO and its Category II centres such as the International Centre for Engineering Education (ICEE), based at Tsinghua University, China and the International Science Technology and Innovation Centre (ISTIC), based in Malaysia, for capacity building such as the projects on climate change education in Mauritius and other Small Island Developing States (SIDS), engineering education standards and development of engineering entrepreneurship, especially for women and girls [26].
- The World Federation of Engineering Organisations is also developing the capabilities of engineers in its member institutions through guidance for the implementation of smart and innovative technologies. It has developed ethical principles for the responsible use of data [27], a report on implementation of smart technologies for cities [28], and a road map for the implementation of geospatial engineering in building and construction [29]. The use of online technologies such as courses and webinars and a knowledge hub also promote transfer of technology and skills [10 op.cit].

WORLD ENGINEERING DAY FOR SUSTAINABLE DEVELOPMENT

World Engineering Day for Sustainable Development was declared by UNESCO in November 2019 is celebrated on 4 March every year as a UNESCO Day of celebration of engineers and engineering from 2020 onwards [30, 31].

I was proud to lead the proposal for World Engineering Day as President of the World Federation of Engineering Organizations. This Day recognises the important role of engineering in achieving the UN Sustainable Goals. 4th March is the founding day of the Federation and is an opportunity to celebrate engineers and engineering collectively around the globe and to engage with the community, government and policy-makers on the important role of engineering in modern life.

80 letters of support were received from international and national institutions, academies and national commissions to UNESCO, representing 23 million engineers around the world with an estimated impact on 2 billion people. As a result of committed and sustained advocacy by the Federation in 2018 and 2019, this resolution was supported unanimously by member States of UNESCO from every continent. This widespread support demonstrates the recognition by governments of the important role of engineering in sustainable development.

The logo conveys the role of engineering and sustainable development around the world and is accessible to everyone. Coordinated celebrations for World Engineering Day worldwide are an opportunity to increase the profile of engineering and to gain media coverage for key events. Social media channels engage with young people in particular and institutions that celebrate the event will be asked to register their events through a dedicated website to build momentum for the celebrations. These are expected to grow each year and increase in importance as each nation celebrates engineering and makes World Engineering Day their own [30 op.cit].

World Engineering Day for Sustainable Development is an opportunity to engage with government and industry to address the role and impact of engineering on the economy and society and the need for engineering capacity and quality engineers around the world, and to develop strategic frameworks and best practices for the implementation of engineering solutions for sustainable development. It is also an opportunity to encourage young people to consider the opportunities of engineering as a career with the message, "If you want to change the world, become an engineer". The Institution of Engineers (India) is an important contributor to celebrations of the Day and will no doubt engage with young people in India to encourage their interest in engineering as a career.

CONCLUSION

Under my leadership as President of the World Federation of Engineering Organisations in 2017-2019, a clear vision and narrative was developed and adopted on the key role of engineering in advancing every one of the UN Sustainable Development Goals. These Goals require an integrated approach to development. As engineers, we need to develop the solutions that are needed to serve people everywhere, protect our planet and ensure prosperity for all. This can only be done in partnership with each other and in doing so we will also ensure a peaceful world.

However, this is no easy task. As engineers, we need to be smarter, learn faster and be more creative and innovative that ever before because we have a great responsibility – we are the change makers, with the skills and the ability to change the world – for better or worse. As engineers we need to use our skills wisely and responsibly. It's about engineering with impact, not just building the biggest, the brightest and the shiniest but a more thoughtful approach to engineering and its implications on our society and on our world. The work of engineers has never been more important or relevant to the needs of our society and our country, today and in the future.

The World Federation of Engineering Organisations is committed to working with its members, including The Institution of Engineers (India), to lead initiatives for sustainable development through engineering, essential for a better, sustainable world.

Table 1: Engineering a sustainable future in India

SDG	The important work of engineers in India
1 NO POVERTY	Engineers are crucial to economic growth in India, not only to develop infrastructure but also technologies that are accessible to people with low incomes, especially in rural areas. For example mobile phones and communications are widely available at low cost, enabling users to better manage their work, farm produce and finances and for better health, education and economic outcomes (see SDG3, SDG4 and SDG8) [16], [32].
HUNGER	Agricultural, mechanical and chemical engineers have transformed food production in India with mechanisation, fertilizers and pesticides. Digital innovations and communications via smartphones to the remotest villages for weather, marketing and other information and smart sensing technologies that optimise soil moisture and irrigation water consumption are increasing production and reducing costs [33].
3 GOOD HEALTH AND WELL-BEING	Engineering has improved the health of Indian citizens by reducing the impact of diseases such as typhoid and cholera through improved water and sanitation. Biomedical engineering advances provide low cost access to health technologies, such as electrocardiograph machines, ultrasound machines, prosthetics and devices that facilitate medical procedures, such as cataract eye surgery [34].[35] [36]. Indian government policies are also supporting "Make in India "for coronavirus responses and telemedicine [37] [38].
4 QUALITY EDUCATION	Education at every level –primary, secondary and tertiary – is a key enabler of development (Roser and Ortiz-Ospina, 2019). Indian engineers are facilitating education delivery through online learning technologies that rely on fast telecommunication and innovations that provide inclusive, low cost solutions such as the 'Aakash' or 'Ubislate' tablet, available for US$ 35 [39]. With over a billion students impacted globally by lockdown measures and unable to attend school, telecommunications networks have been crucial in sustaining inclusive learning opportunities for all, a significant paradigm shift which will have impact beyond 2020 [40].
5 GENDER EQUALITY	Closing the digital gender gap will ensure that Indian women will benefit from engineering and telecommunication innovations in finance, agriculture, health, personal safety, education and other applications [41] [42] [43]. The participation of women in technology and engineering in increasing in India, ensuring diverse inputs for innovative solutions that reflect community culture, values and aspirations [44].
6 CLEAN WATER AND SANITATION	Civil and environmental engineers in India, have saved billions of lives through technologies designed to provide clean water and treat sewage. Electrical and mechanical engineers continue to ensure that these systems operate reliably. Since the launch of the Swatchh Bharat Mission in 2014, over 100 million toilets have been built in rural areas and 35 States declared Open Defecation Free (ODF). India now aims to transition sustained ODF and to provide piped water to all by 2024 [45].

SDG	The important work of engineers in India
7 AFFORDABLE AND CLEAN ENERGY	Around 750 million people in India gained access to electricity between 2000 and 2019 with the Government of India announcing that electricity was available in every village in India. Electrical, mechanical and environmental engineers have been central to "Make in India" low-cost renewable energy solutions, especially solar and wind which are expected to supply 40% of demand by 2040, providing access to electricity in remote regions while mitigating the impacts of climate change. Such access is also supporting agriculture through the operation of irrigation pumps, enabling refrigeration for food and medicine, and providing power for household appliances [46].
8 DECENT WORK AND ECONOMIC GROWTH	Incomes in India have increased quickly in recent years and millions of have been lifted out of poverty. India has also become a key player in the global economy [47]. However, more engineers are needed for economic growth. [8, op.cit]. Roads, railways, airports, water supply and electricity, and telecommunications are essential infrastructure underpin the economy. All are designed, developed and maintained by civil, mechanical, electrical and environmental engineers. Clean water, energy and housing are basic amenities, also developed by engineers, that enable citizens to maintain healthy, productive lives and engage in decent work. [48].
9 INDUSTRY, INNOVATION AND INFRASTRUCTURE	Engineers in India have mastered the art of "frugal innovation "with "Jugaad" - a uniquely Indian approach to innovation that uses minimum materials and is low cost. [49]. Indian engineers designed and developed the Tata 'Nano' car, a breakthrough in low-cost transport, with numerous innovations and a low weight of just 600 kg. India is the 3rd largest start-up country in the world with more than 20,000 start-ups mainly in the technology sector, driving digital innovations in e-learning, health, virtual shopping and payments systems, creating new industries and jobs [50].
10 REDUCED INEQUALITIES	In India, engineers and engineering are making an essential contribution to reducing inequalities through the development of infrastructure (see SDG 8) and new technologies and innovations (see SDG 9) that create jobs and provide opportunities for everyone. Ensuring access to the latest low-cost communications and mobile phones, information and education, low-cost medical diagnostics and treatment (see SDG 3); and national data and identity systems such as the Aadhar card and low cost household appliances like the Chotookool Fridge are essential for workforce participation [4, op.cit] [51].
11 SUSTAINABLE CITIES AND COMMUNITIES	Indian cities are growing rapidly, with 100 smart cities impacting nearly 100 million people planned by 2022. Civil, structural, electrical, mechanical, environmental and software and telecommunications engineers in India are important for liveable, sustainable and resilient cities. They are essential for sustainable smart cities that incorporate energy efficiency into buildings, smart lighting, efficient transportation systems, renewable sources of energy and effective water resource management. [52] [53] [54].
12 RESPONSIBLE CONSUMPTION AND PRODUCTION	Mining, civil, mechanical, electrical and environmental engineers play critical roles in managing resources efficiently from mining, processing essential minerals, generating energy from renewable resources, ensuring the effective use of water resources, agricultural production and the management of biodiversity. Engineers are developing solutions for resource management and responsible consumption through the concept of the circular economy, where outputs and products can become inputs into other processes and products thereby conserving the Earth's resources. [55].

SDG	The important work of engineers in India
13 CLIMATE ACTION	Indian engineers have led the reduction of greenhouse gas emissions by more than 20% over the past decade and India is committed to meeting its Paris Agreement targets [46 op.cit]. Engineering technologies for renewable energy generation and resilient infrastructure mitigate climate change impacts with huge economic and social benefits and enable faster recovery from natural disasters [56].
14 LIFE BELOW WATER	Marine engineers in India are working with scientists and other engineering disciplines to implement solutions to address the degradation of fisheries, the pollution of oceans the reduction of plastic pollution and the use of resources, including wave energy and oil and gas exploration. Addressing plastic waste is a prirotiy as it is slow to biodegrade and breaks down into micro-plastics that harm marine life, starving them of food and causing entanglement, eventually affecting the food chain for humans.[57] [58] [59].
15 LIFE ON LAND	Engineers are essential for the sustainable management of forestry resources which are an important source of livelihood in India. The Government of India Code for forestry management uses science and technology to preserve forest habitats. Engineers at FAO and NASA are using geospatial technologies and satellites to map the Earth's surface to monitor flora, fauna and the impacts of climate change and to predict and mitigate bush fires and other natural disasters. [60] [61] [62].
16 PEACE, JUSTICE AND STRONG INSTITUTIONS	Peace, justice and inclusive societies through good governance and strong institutions is a priority for everyone including engineers. The World Federation of Engineering Organizations (WFEO) is partnering with its members and partners in international engineering for new engineering education benchmarks that will reflect the values of sustainable, ethical and inclusive engineering. The projects will develop strong accreditation and professional engineering institutions to regulate engineering education systems and support ongoing professional development of engineers [23 op.cit.]. The WFEO Model Code of Ethics [27 op.cit] has been adopted by members around the world [63]. (Engineers Australia, 2019). WFEO is also contributing to the development of international standards on governance and anti-corruption and to mitigate climate change impacts. [64] [65] [66].
17 PARTNERSHIPS FOR THE GOALS	Partnerships in engineering are essential to advancing the goals of sustainable development, not only for solutions but to build capacity and knowledge transfer mechanisms. The World Federation of Engineering Organizations (WFEO) is working with UNESCO and signed the Paris Declaration in March 2018 as a statement of commitment to advance the UN Sustainable Development Goals through engineering [21 op.cit]. WFEO is also collaborating with the International Engineering Alliance, the International Federation of Consulting Engineers (FIDIC), the International Network for Women Engineers and Scientists (INWES) and the International Federation of Engineering Education Societies (IFEES) on engineering education standards, diversity and professional development [23 op.cit].

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Author's Profile

Dr Ajay Mathur, during his stint at TERI, has spearheaded the move to accelerate action towards a low-carbon and cleaner economy through the promotion and adoption of renewable energy and green hydrogen in the Indian electricity sector, enhancing efficiency in buildings and industry, and promoting environmental quality through institutional and policy measures to enhance air quality across the country, adoption of resource efficiency and waste recycling measures, and biotechnology-based solutions, especially for agricultural and industrial environment improvement.

He co-chairs the global Energy Transitions Commission; is also co-chair of the Clean Cooling Initiatives of the One Planet Summit.

He earlier headed the Indian Bureau of Energy Efficiency, and was responsible for its foundational programmes which mainstreamed energy efficiency through initiatives such as the Star Labeling programme for appliances, the Energy Conservation Building Code, and the Perform, Achieve & Trade programme for energy-intensive industries. He was a leading climate change negotiator, and was the Indian spokesperson at the Paris climate negotiations. He served as the interim Director of the Green Climate Fund during its foundational period.

Dr Mathur received a Bachelor's degree in Chemical Engineering from the (then) University of Roorkee, and Masters and Ph.D degrees from the University of Illinois. He has also received the Distinguished Alumnus Awards from both his alma maters.

He was appointed a Chevalier de l'Ordre national du Merite by the President of France in recognition of his outstanding commitment to the preservation of the environment and coping with energy-related challenges.

The Electricity System of Tomorrow – Evolving a Revolution

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ABSTRACT

We are living through an unprecedented social and technological transformation of the Indian electricity sector. The patterns of electricity demand and supply are both changing; access in now almost universal; electricity end-use efficiency is rising rapidly; and renewables now provide the cheapest electricity when the sun is shining and the wind is blowing. In addition, climate change concerns are accelerating the need for reduction in the carbon intensity of electricity consumption. As a result, the electricity sector of tomorrow will be very different from that of yesterday: the demand will be more volatile; new generation capacity will be renewables-based; and balancing demand and supply will be the key challenge. This highlights the need for "managed flexibility" in electricity sector management, and underscores the need for a portfolio of flexibility options, as well as of research and capacity building for designing and implementing technical, economic and regulatory interventions to manage flexibility.

However, for the technical and economic evolution to become an electrical sector revolution, the institutional and governance structures will also need to evolve so as to exploit the techno-economic benefits and pass them on to electricity consumers.

This paper focuses on the great transition that the electricity sector in India is undergoing, and that we have the privilege of living through. Such transitions occur but rarely in History, when we undergo changes, not just in magnitude and diversity, but in the very principled and structural frameworks that form the basis of our understating. Now, the focus is on the evolution of the Indian power sector to high shares of variable renewables, like wind and solar. The following section gives a brief overview of the current pattern of production and consumption of electricity. The next section surveys recent technology developments. The following section examines demand forecasts, focusing in particular on the role of cooling in driving future demand. After this, the penultimate section looks at the options and challenges for integrating variable renewables into the power sector. The concluding section offers some reflections on the political economy of electricity sector transition in India, and the long term revolution that is being created.

THE EVOLUTION TILL NOW

Changes of the first type – in magnitude and diversity – are what we have witnessed till now. In 1947, when India gained independence, the country had an installed electricity capacity of less than 14 GW[1], and an electricity supply shortage, which was conservatively estimated as 6%. More significantly, a little over 3000 (of the approximately one million) villages were connected to the electricity grid, and India's electricity generation was 17 kWh per person per

1. Interpolated from data in Economic Survey 2017-18, Statistical Appendix, Table 1.25A

year[2]. And despite adding 1 to 2 GW of installed capacity per year during 1960s and 1970s, and 3 to 5 GW of installed capacity per year during the 1980s and 1990s, the energy shortage kept growing, from 6% in 1982 to 8.3% in 1992 and to 8.8% in 2002.

Today, the situation is quite different: as **Fig. 1** shows, installed capacity in 2017 was 240 times that in 1947, and electricity consumption was 255 times that in 1947. More significantly, household connectivity has grown rapidly as can be seen in **Fig. 2**. In 2019, nearly 100% of households have been connected into the grid. The electricity generation capacity connected to the grid is nearly 350 GW, and the maximum demand in 2018 was less than 180 GW. The era of electricity supply shortages is over; **Fig. 3** shows that both energy and peak deficit have declined to near-zero now. Any brownouts or blackouts that occur today are because of distribution-level problems, and not because of supply shortage. Electricity generation has increased to over 1000 kWh per capita per year, though it is still only one-fourth of the global average.

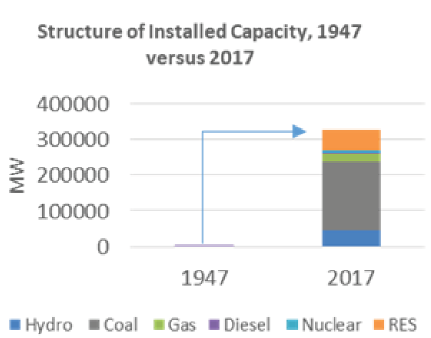
2. Most data has been sourced from various issues of All India Electricity Statistics, General Review, an annual publication of the Central Electricity Authority, and from the website of the Ministry of Power.

ELECTRICITY DEMAND GROWTH: AIR CONDITIONING IS THE PRIME DRIVER

As we look to the future, it is clear that the electricity demand would continue to increase; largely because increases in electricity use are an essential component in the enhancement of the quality of life. Statistically, all countries in the world which have been able to achieve a Human Development Index (a surrogate of the quality of life) of 0.9, on a scale of 0 to 1 with 1 representing an extremely good quality of life, have achieved electricity supply of at least 4000 kWh per capita per year[3]. In other words, as India ensures a high quality of life for its citizens, it will have to quadruple its energy supply.

The good news is that while some countries have been able to achieve a HDI of 0.9 with an energy consumption of 4000 kWh per capita per year, there are other countries which require up to two-and-half times as much electricity to reach the same HDI. In fact, countries that have industrialized and developed later in history have used less electricity to reach the same HDI level. This is primarily because countries that developed later are able to utilize more energy-efficient equipment and infrastructure. Consequently, it would not be surprising if India is able to move

3. TERI analyses based on UNDP, Human Development Report, 2019, and World Bank, World Development Indicators.



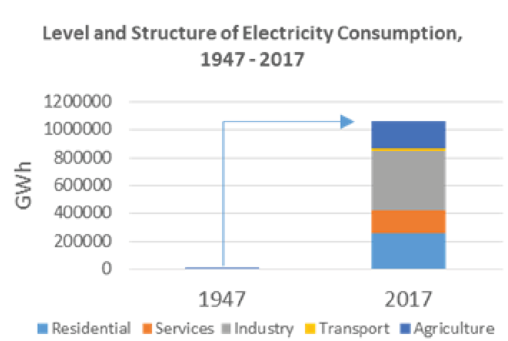


Fig. 1 : Electricity consumption and installed capacity have both increased by nearly 250 times in the 70 years since Indian independence

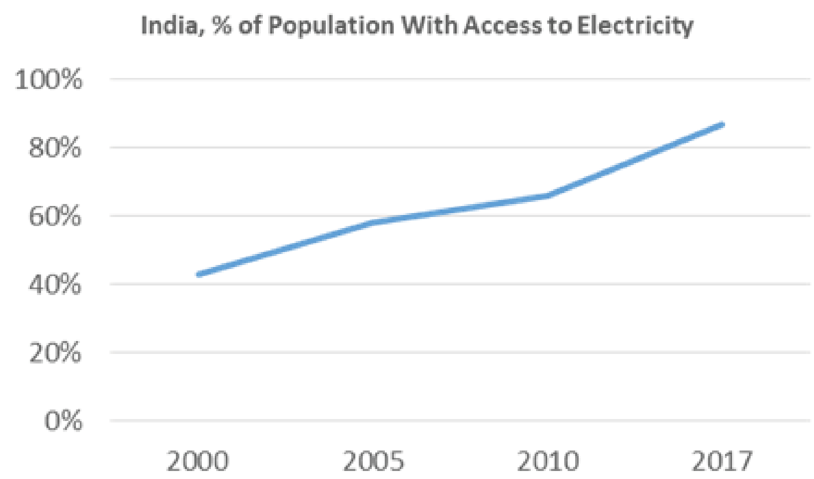


Fig. 2 : Electricity connectivity grew rapidly in the first two decades of this century; it is now nearly universal

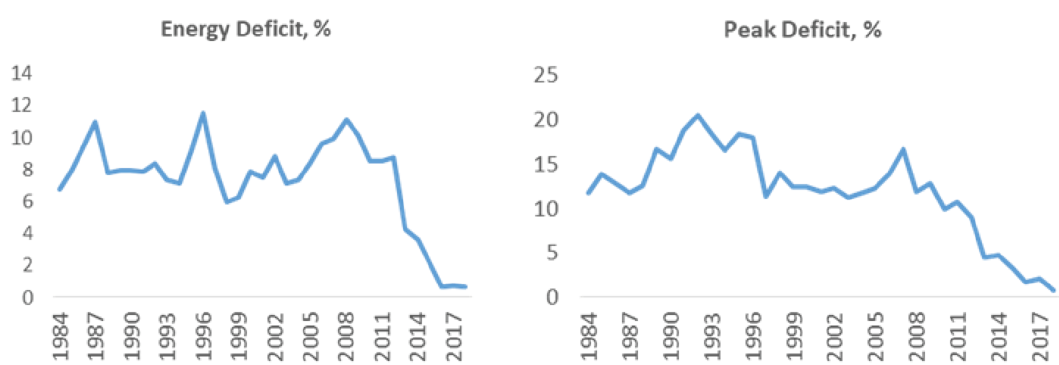


Fig. 3 : Energy and peak deficits have declined to near-zero levels

from the current HDI of 0.6 (with an electricity supply of 1000 kWh per capita per year), to a HDI of 0.9 with electricity supply in the range of 2500 to 3000 kWh per capita per year, instead of 4,000 kWh per capita per year, as current statistics would suggest. However, even that lower level of electricity requirement, would still necessitate a near trebling of the electricity supply in the country.

The question of course is whether Indian energy efficiency trends would move at this required pace.

Statistically, this is possible. In the past 15 years, the energy intensity of the Indian economy i.e. the amount of energy used for producing each rupee of GDP, has been declining at about 2.5% per year, one of the fastest decreases in the world. We have projected that if the current rates of GDP growth and of energy intensity decline continue over the next 20 years, India could expect to achieve a high HDI (in the 0.85 to 0.9 range) with electricity supply in the range of 2,500 to 3,000 kWh per capita per year, that is 2.75 times the current per capita electricity supply.

The second issue to consider is where will this electricity demand growth come from? While electricity demand would certainly come from the increased use in the industrial sector, as well as

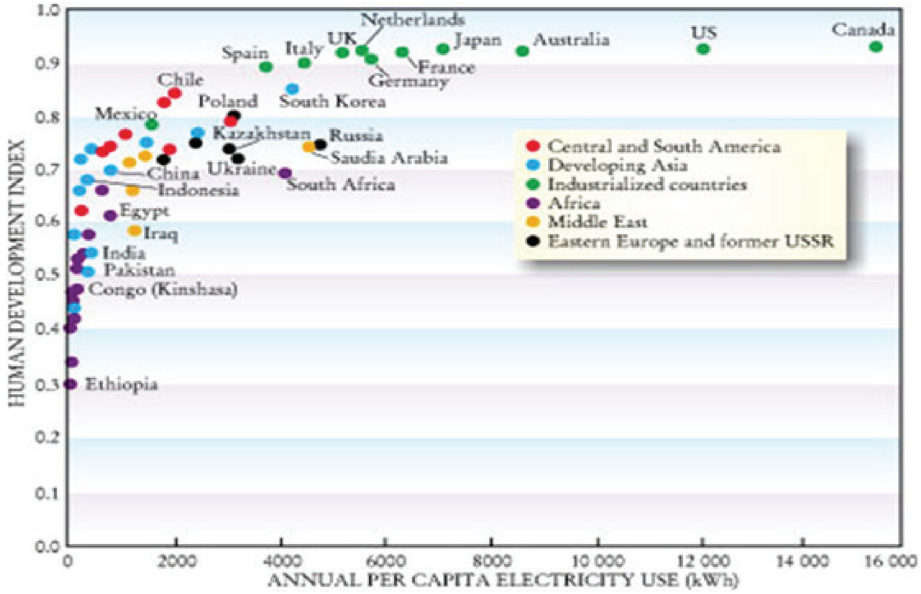


Fig. 4 : Countries with HDI of over 0.9 have needed to enable electricity use of at least 4,000 kWh per person per year; countries that industrialized later have required less electricity than those which industrialized earlier

from new usage areas such as electric mobility, the largest growth is expected to occur because of the increased adoption of air conditioning. This is, in a sense, both expected and desirable. Expected because India consists of the largest agglomeration of population in the world living in hot and humid climates[4]. Consequently, the overall need for providing every person with an environment of human comfort requires a lot of air conditioning. And, desirable, because of the huge productivity increases associated with working in environment where human body works in thermal comfort[5].

Using a variety of forecasting methodologies, TERI has triangulated the electricity demand in 2030 to be between 2040 and 2973 Terra Watt hours, based on GDP growth and energy efficiency

4. Lucas Davis, Air Conditioning and Global Energy Demand, Energy Institute at Haas, Energy Institute Blog posted April 27, 2015, https://energyathaas.wordpress.com/2015/04/27/air-conditioning-and-global-energy-demand/, accessed on 18th October 2020.
5. William Nordhaus, Geography and Macroeconomics: New Data and New Findings, Proceedings of the National Academy of Sciences USA, 2006, March 7, 103(10), 3510-3517.

Table 1 : Assessment of Cooling Degree Days (CDDs) in various countries; the potential air conditioning requirement would be the multiplication of the CDDs and the population[6]

Air conditioning potential, top 12 countries

Country	Population (in millions)	Annual CDDs	Annual GDP Per Capita (in thousands)
India	1252	3120	1.5
China	1357	1046	6.8
Indonesia	250	3545	3.5
Nigeria	174	3111	3.0
Pakistan	182	2810	1.3
Bangladesh	157	2820	1.0
Brazil	200	2015	11.2
Philippines	98	3508	2.8
United states	316	882	53.0
Vietnam	90	3016	1.9
Thailand	67	3567	5.8
Mexico	122	1560	10.3

6. Thomas Spencer and Ayushi Awasthy, Analysing and projecting Indian Electricity Demand to 2030, TERI, 2019

increase assumptions[7]. Our best guess is that the total demand of electricity wold be in the vicinity of 2300 TWh, compared to the 2017 demand (not supply) of 1130 TWh.

CURRENT TECHNOLOGICAL & ECONOMIC EVOLUTION

There are two challenges associated with meeting this demand. The first is where will this electricity supply come from? What will be the fuel source; an issue of importance because of the Indian commitment to the United Nations Framework Convention on Climate Change (UNFCCC), that at least 40% of the total generating capacity in the country would be based on non-fossil fuels. In 2015 when this commitment was made, about 30% of the electricity capacity was based on non-fossil fuel and wind, solar, hydro and nuclear, and over 60% was based on coal generation. Consequently, the vast amount of the new electricity generation capacity that is added would need to come from the non-fossil fuel sources.

The second challenge is to meet the demand while catering to the change in load curve profile. The maximum amount of electricity, on a daily basis, has been and is consumed in the summer and monsoon months, i.e., in the approximately 200 days between mid-March and mid-October. Till a decade ago, the maximum demand, during this period of the year, used to occur at about 7 and 8 PM (on about 190 days); on a few days (less than 10 days), the peak occurred at 9 PM. However, during the past decade, the nature of this peak has changed: it has steadily lengthened, and the number of days when the peak is at 7 or 8 PM is now about 150, and on the balance of days, the peak occurs, with about equal frequency, at 9, 10 and 11 PM. This reflects the growing penetration of air conditioning in households, and the utilisation of this at night as people come home from work. Already in some jurisdictions, such as Delhi, the maximum annual peak occurs at 11 PM on a late-August/early-September night, and possibly reflects the future, in as much as Delhi, as the richest state in the country, exhibits air-conditioning adoption trends that we will see tomorrow in the rest of the country. It can be expected that as incomes increases and as household air conditioning increases, the night peak would become even longer and spikier. Consequently, apart from the challenge of meeting the increased energy demand in a cleaner manner, there is also an additional challenge of meeting it late in the night.

The good news is that it seems feasible that we may be able to meet both these challenges, certainly before 2030, though the transition will not be simple and straightforward. The prime reason for this optimism is the sharp decline in the price of electricity from renewables (particular solar and wind electricity), and the increasingly sharp decline that continues to occur in the cost of battery storage. Already, electricity from solar and wind energy, at Rs. 2.44 per kWh costs less than coal electricity at Rs. 3.70 per kWh (and the LCoE for a new pithead plant is Rs. 3.64/kWh, and the average LCOE for a new non-pithead power plant is about Rs.4.97/kWh), when the sun is shining and the wind is blowing. However, by itself solar and wind energy would not be able to meet the 7-11 PM peak. This is where storage becomes important.

TERI has projected[8] that renewable electricity, with battery storage, would be cheaper than coal electricity in providing electricity on a firm 24-hour basis by the late 2020s. This implies that by the end of the decade of the 2020s, consumers, distribution companies, generation companies, and Banks would prefer buy and invest in renewables rather than coal plants. This would reflect a major transition in the Indian electricity sector, and even though coal would continue to be a major source of electricity for at least two more decades - till the existing coal power plants retire and are

7. Thomas Spencer and Ayushi Awasthy, Analysing and Projecting Indian Electricity Demand to 2030, TERI, 2019.

8. Raghav Pachouri, Thomas Spencer and G Renjith, Exploring Electricity Supply Mix Scenarios to 2030, TERI, 2019.

replaced by new capacity based on renewables + storage. This future seems to hurtling toward us at an accelerated pace – in May 2020, a SECI tender has discovered a price for round-the-clock renewable electricity to be supplied in two years, from solar PV and battery storage, at Rs.2.90 per kWh in the first year, escalating at 3% per year till the 15th year of supply[9].

BALANCING DEMAND AND SUPPLY: THE EMERGING ELECTRICITY SECTOR CHALLENGE

We expect therefore that the major challenge to electricity sector management would be balancing the demand and supply, primarily because the cheapest form of electricity generation (renewables) would occur at a time which is different from what the maximum demand (home air conditioning at night) occurs. "Managing flexibility" is therefore of prime importance. We have noted earlier renewable electricity is already the cheapest form of electricity at the time of generation. We have also noted that, in about 10 years, storage technologies would be inexpensive enough so that renewable+storage are the sources of cheapest 24-hour firm electricity supply. In this 10-year interregnum, the balancing of coal+renewable supply and end-user demand requires strategic operational management and investment decisions so that, on the one hand the total cost of electricity supply does not increase, and on the other hand, reliability of supply continues to increase.

In a recent study, CPI and TERI[10] studied the managed flexibility options that are available to the Indian electricity sector. We note that currently this flexibility is provided by existing coal power plants which ramp down during the times when wind and solar energy are available, and ramp up as the production of variable renewable electricity declines. We suggest therefore that ramping up and ramping down of coal power plants is the first and the least-cost managed flexibility option, primarily because coal power plants have already been built, and the cost of flexibility is the difference between the cost of renewable energy (which, at the margin, is priced at Rs. 2.44 per kWh) and the variable cost of coal electricity generation (i.e. largely the cost of coal used in the generation of this electricity, which is about Rs. 2 per kWh). The Central Electricity Authority has recommended that all supercritical coal-based power plants have ramping capacity of ±3% of rated capacity per minute[11]. Recently, Siemens, Steag, and NTPC have experimented on stable operation of coal power station at 40% load and issued protocols for this operation[12]. Currently, efforts are ongoing for stable operation even at lower capacity factors. It also seems possible, based on the experience of super-critical power stations in Germany that ramping rates that are higher than the CEA guidelines are possible. In other words, technological interventions at enhanced ramping rates while ensuring stability of operations is the challenge in achieving managed flexibility.

The second option for managing flexibility is demand reduction. This intervention is based on the regulator providing a discount in the period for those users who are able to achieve a significant reduction in their load in a very short time period. This would enable demand to be reduced rapidly enough so that reduced supply (due to, for example, reducing solar generation in the evening hours) can meet the reduced demand. As few distribution companies, for example, Tata Power Delhi Distribution Limited (TPDDL) in North Delhi, have experimented with such measures, though without the economic incentive of reducing performance, but are able to reduce

9. https://mercomindia.com/renew-power-seci-round-clock-renewable-tender/, accessed on 18th October 2020.

10 Udetanshu, Brendan Pierpont, Saarthak Khurana and David Nelson, Developing a roadmap to a flexible, low-carbon Indian electricity system: interim findings, Climate Policy Initiative (CPI), 2019.

11. Standard Technical Features of BTG System for Supercritical 660/800 MW Thermal Units, Central Electricity Authority, July 2013.

12. B P Rao, Steag, Personal Communication, 2018.

demand in short notice. The TPDDL pilot focussed on 161 industrial and commercial consumers with sanctioned load of 63.5 MW. The aggregated average demand of these consumers was about 30 MW (ranging between 26 and 32 MW) on the 9 days that they were asked to reduce demand at short notice. On an average, the consumers were able to achieve aggregated average demand reduction of 5 MW (ranging between 3.04 and 7.22 MW) within one hour of the start of the DR reduction event. There was also a strong learning experience: in the first three events, the reduction was less than 3.8 MW; the reductions exceeded 4 MW in the last six events, with an average reduction of 6.28 MW, or about 20.7%[13]. Further the increasing use of air conditioning suggests that quick demand reduction opportunities also exist in the residential and commercial sectors: if users can change their air conditioner set points from 22 ^{O}C to 26 ^{O}C, it can result in demand reduction of up to 12%[14]. These suggest that large-scale demand reduction measures can be a successful component of managed flexibility; the Delhi Electricity Regulatory Commission has allowed, on a 2-year experimental basis, a 20% discount on commercial and industrial tariffs for consumers who are able to respond to DR events with more than 2 hours notification, and 40% discount in case of event with less than 2 hours notification.

The third and last component of the managed flexibility that the TERI-CPI study looked at is storage, both through pumped hydro projects and batteries. This is, as has been mentioned earlier, an expensive proposition today, but declining costs suggest that it could be cost effective by the middle of the 2020s. The greatest challenge in enabling storage is enabling the appropriate changes in system operation and management. Storage components in a system would require that they (batteries/pumped hydro) are charged whenever there is potential for excess generation (i.e., generation exceeds demand), and drained whenever there is excess demand.

This completely negates the received paradigm of balancing generation and demand in real time, which is the basis of system operation principles today. The operating protocols for this changed operating process are yet to be established. A recent 10 MW battery storage system installed by AES and Mitsubishi for Tata Power in North Delhi[15] suggests that batteries are never charged or drained to 100% or 0% respectively. The early results also suggest that the availability of the storage enables quick frequency correction as well[16].

A major challenge in operationalizing storage is the development of a regulatory framework for incentivizes storage capacity to give online. Storage capacity is expensive and is used for a relatively short period of time at least in the next few years while the share of variable renewable electricity is still less than 10%. Consequently, investors in storage capacity do not see their investments providing returns. The CERC has brought out a discussion paper[17] which proposes a framework in which all electricity supply would be provided through the exchanges, leading to large-scale price discovery in each time slot of electricity supply. This process suggests an interim period, in which there could be contracts for difference (to compensate generators / discoms) if the market clearing price deviates from the Power Purchase Agreements (PPAs) in place, followed by a regime which would completely eliminate long term power purchase agreements, and would introduce the time-of-supply pricing at the bulk level (which is very different both in practice and in operation from the time-of-day tariff for

13. Ganesh Das, TPDDL, TPDDL Automated Demand Response, Powerpoint presentation dated 3rd February 2017, personal communication, 15th April 2019.
14. www.meitavtec.com/EnergySaving/EnergySavingTips.pdf, accessed on 18th October 2020.
15. Economic Times, Tata Power commissions South Asia's largest grid-scale energy storage system, 13th February 2019
16. Rajendra Shrivastav, AES, personal communication, 5th April 2019.
17. Central Electricity Regulatory Commission, Discussion Paper on Market Based Economic Dispatch of Electricity: Re-designing of Day-ahead Market (DAM) in India, December 2018

retail). It is to be noted that the discussion paper proposes an interim period in which there will be contracts for difference to compensate generators or distribution companies if the market clearing price deviates from the PPA price. This approach would incentivize investment in storage capacity since it would provide the price signal, of higher supply prices during the night peak, necessary to provide comfort to investors.

CONCLUSIONS – WILL EVOLUTION BECOME A REVOLUTION?

The Indian electricity system in 2020 is undergoing a great transition, driven primarily by the rapidly declining price of variable renewable electricity (primarily wind and solar) and the ongoing decline in the price of batteries. Together, these have the potential to replace coal as the preferred source of electricity supply. On the other hand, the increasing demand for air conditioning is changing the nature of the demand load profile which could be further exacerbated as new users of electricity, such as electric vehicles and their charging needs, come online.

We suggest therefore that balancing demand and supply, over various time periods – over a day, over seasons, and over years – is emerging as the greatest challenge in the electricity sector, and requires technical, economic, and regulatory interventions to ensure that cost of electricity supply keep declining while reliability of its supply keeps increasing.

We also suggest that there are at least three flexibility options to manage dissonance between demand and supply. These are: the rapid ramping up and ramping down capacity of coal power stations; demand reduction interventions; and addition of storage capacity to the grid. All of these managed flexibility options are currently under development, and used together in a portfolio mode to have the potential to satisfy the price, demand and reliability challenges of the transition.

This vision advanced in this paper is technically completely achievable, and seems to be-over time-becoming economically viable as well. However, we note that technical feasibility, economic viability and political expediency need to be balanced for the evolution in any of these three pillars to become a sectoral revolution.

In view of the relatively limited evolution in the political economy and governance of the Indian electricity sector, a few concluding remarks are in order. First, it is accepted that the power distribution companies in India are in a perilous financial situation, which has been aggravated by the financial losses suffered by them during the COVID-19 lockdown when they lost their industrial, highest paying consumers. The lack of (financial, technical and manpower) resources imply that the distribution companies (especially those owned by state governments) are unable to upgrade their technical and managerial capacities to both manage the increasing volatility in demand and supply, and invest in the technical infrastructure required for balancing. This has made state governments and regulators apprehensive about introducing the institutional and governance changes that are necessitated by the changes in technology and in economics.

Second, while rural supply, and principally the subsidized electricity supply to agricultural pumps, is at the heart of the political economy which favours the status quo (and is apprehensive of institutional and governance changes necessitated by changes in technology and in the comparative economics), the emerging answer to this vexed issue seems to lie in the broad application of solar PV electricity for agricultural water pumping. This application has limits – for example, solar PV pumping may not be economically effective in drawing water from the depleted aquifers in Punjab and Haryana – but it provides, for many distribution companies, an option to reduce the cost of rural electricity supply by setting up rural PV electricity generation plants. In the past few months, the electricity distribution companies in Maharashtra, together with EESL, have created[18]

18. https://www.eeslindia.org/img/news_m/EESL_April_Newsletter.pdf, accessed on 19th October 2020.

a number of up to 2 MW grid-connected solar plants (totalling about 100 MW as at the end of September 2020) to supply daytime electricity to agricultural pumps, reducing the cost of supply at rural feeders to Rs. 3 per kWh, from the existing level of over Rs. 5 per kWh.

Third, in urban areas, the franchisee model has yielded effective results in enhancing reliability of supply, holding down cost of supply, and enabling a positive return on investment[19].

Together, these trends imply that some distribution companies will prod the state governments and regulators to change the institutional and governance models. However, the rate at which initial change occurs will be determined by larger political economy issues around the transparency in providing services, and in the setting of electricity tariffs, as well as in the macro-economic ability of the states to sustain losses in the electricity sector.

The revolution is evolving.

19. Performance Assessment of Electricity Distribution Franchisee of Agra, TERI, 2018.

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Author's Profile

Shri Vijai Kumar Agarwal, is the former Chairman of Indian Railways and Ex-Officio Principal Secretary to the GOI, and one of the leading technocrats of the country is also an author of repute having penned a book titled, "Managing Indian Railways – The Future Ahead".

He has also been writing articles on diverse topics like Science & Spirituality; Environment & Ecology as well as on promoting and trying to re-energise Engineering as a profession apart from writing on Railways. Currently he Chairs the Technology Foresight and Management Forum for Addressing National Challenges constituted by the Indian National Academy of Engineering.

Role of Engineers in Policy Making

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EVER-INCREASING ROLE OF ENGINEERING IN GROWTH / PROGRESS / DEVELOPMENT

Science / Technology / Engineering are closely associated with growth / progress / development in all walks of life. Although broad definitions differentiating them have evolved over time but these are not explicit and technology (especially Applied Technology) and engineering are many a times considered part of science only.

A look into the yore years will indicate that the profession of engineering had a lead role delivered through leading engineering colleges like Thomson College of Engineering, Roorkee and College of Engineering, Guindy in India and Imperial College of Engineering in UK. In 1950s the scenario appears to have started changing when leading engineering colleges became more technology oriented like the Massachusetts Institute of Technology in USA and the Indian Institutes of Technologies in India.

It is felt that position is fast changing / changed in favour of the profession of Engineering which is poised to play a lead role. The UNESCO Report (2010) titled "Engineering, Issues, Challenges and Opportunity to Development", which tries to make the boundaries between Science / Technology / Engineering more explicit, provides ample testimony to this fact. Box 1 includes the aspect of engineering using theories from science and tools provided by technology provide products and benefits to society / nature with an eye on the resources and the needs. The emerging major issues are that till recently we were not very considerate towards nature and main emphasis was on society alone and further the growing needs and depleting resources were not given adequate focus. The position with regard to increasing role of engineering has been future amplified and a list of various Engineering Branches has also been provided (See Box 2) which will elaborate that practically all areas of human interest, activity and endeavour have a branch of Engineering associated with it.

This also poses engineering with lots of ethical issues requiring different approaches to problem solving. To give a flavour of one such issue one may refer to Box 3 which briefly discusses environmental ethics indicating the changed approaches with changing value norms.

MOST OF THE PROBLEMS / ISSUES WHICH THE ENGINEERING HAS TO ADDRESS ARE HAVING A DEEP GLOBAL CONNECT

If one looks at the problems of climate change, ecological destruction and other related issues (Box 4) or major challenges of the 21st Century as enunciated by Sachs (Box 5) or United Nations – Sustainable Development Goals (Box 6), one is overawed to see a large number of interconnected / inter-dependent areas and issues to be tackled on a large time frame, requiring the willing cooperation of world nations, which is a near impossible task. We have to look for innovative solutions.

Further, major problems of our time namely, the ecological destruction, climate change, poverty, energy, and the like cannot be addressed is isolation. They are Systemic problems, which mean they are all interconnected and interrelated. From the Systems point of view the only viable solutions are those that are sustainable.

SUSTAINABLE DEVELOPMENT DEMYSTIFIED

Sustainable Development is the need of the hour. In this regard the following may be referred to understand the connected issues / problems:

(i) Five E's of Sustainable Development (Box 7)

(ii) Sustainable Development – Brundtland Commission (Box 8)

(iii) Sustainable Economics / Ecological Economics (Box 9)

(iv) Lessons on Sustainability from the Ecosystems (Box 10).

GLOBAL COOPERATION WILL NEED A DIFFERENT APPROACH TO VALUES AND TO THE PROBLEM SOLVING

In this direction the following points need to be taken into account:

(i) Shift in norms for Values / Thinking – More Integrative Approach (Box 11)

(ii) Market / Social / Spiritual Values (Box 12)

(iii) Gandhian Engineering (Box 13).

NORMS FOR GROWTH / PROGRESS / DEVELOPMENT ARE CHANGING

These have been briefly discussed in Box 14 (Gross Domestic Product / Human Development Index / Gross National Happiness).

INAE'S TECHNOLOGY FORESIGHT AND MANAGEMENT FORUM FOR ADDRESSING NATIONAL CHALLENGES - PUBLICATIONS

The Indian National Academy of Engineering (INAE) constituted a Technology Foresight and Management Forum for addressing National Challenges (T.F. in short) in the year 2012 with 9 members (5 were INAE Fellows). The T.F. over the years worked on various issues and is also visualised as a think tank for the INAE. Currently, it has 12 Members (6 are INAE Fellows). A look at Box 15 will give a more clear understanding of Technology Foresight whereas; Box 16 gives a feel of the Problem Solving Approach of the Technology Foresight Forum.

The Technology Foresight Forum has published the following Four Reports which can be found on INAE Website:

The First Report (March 2014) covered the following four Areas :

Chapter Title

1. Introductory / Explanatory Notes
2. Waste Management
3. Water – Meeting the Future Challenges
4. Transport – Making it Greener.

The Second Report (March 2016) covered the following three Areas :

Chapter Title

1. Agriculture – Waste Reduction and its Use
2. Energy – Major Thrust on Solar
3. Mass Transit Systems

The Third Report (October 2018) covered the following two Areas :

1. Challenges of Rural Urban Continuum
2. High Speed Rail for India

The Fourth Report (November 2019) covers the following three Areas :

1. Issues of Environment / Climate Change / Sustainability
2. Rail-based Infrastructure Urgently Needs Four Major Interventions at the Level of Government of India
3. Improving the Operating Ratio of Indian Railways – A Way Forward.

These reports can provide Technology Foresight inputs for several areas including Energy, Water, Transportation, Rural Development, etc.

SOCIETY 5.0 – HUMAN CENTRIC TRANSITION STRATEGIES

Society 5.0 will be a Super Smart Society (See Box 17). To make it Human Centric will be an extremely difficult proposition. Methods being contemplated by a developed country like Japan may not suit us. We will have to look for innovative solutions.

CONCLUSIONS

Engineers have not only to play a part in Policy Making but the Engineers / Engineering have a major role in Growth / Progress / Development process (Policy laying; Its implementation; Mid term corrections as needed; Development of new and appropriate technologies according to changing needs and new scientific developments). The suggested Action Plan is given in appended below in the form of a NOTE.

Note on Improving the 'Role' and the 'Image' of Engineering

The Government/Society must recognize the role which Engineering/Engineers are playing in development and should take adequate steps to suitably empower them. In this direction, following are suggested:

1. Boundaries between Science, Technology and Engineering have to be made more explicit. Engineering should no longer be the 'Unsung Partner of Science'.

2. The scope of the present 'Science and Technology Policy' of the Government of India (currently there is no Engineering Policy) has to expand to include 'Engineering' also or else a separate 'Engineering Policy' needs to be developed.

   A more holistic view of science and technology needs to be taken, better integrating engineering into the rather narrow linear model focusing on basic sciences, research and development. To do this, we need to emphasise the way engineering, science, and technology contribute to social and economic development, promote sustainable livelihoods, and help mitigate and adapt to climate change. We also need a better integration of engineering issues into science and technology policy and planning, and of engineering, science, and technology considerations into development policy and planning, in order to reflect a more useful, beneficial and accurate position of reality. This apparently difficult task might best be achieved by taking a more cross-cutting and holistic approach, with greater reference to the important role of engineering, science, technology, and innovation in economic and social development, poverty reduction and climate change mitigation and adaptation.

3. There is a need to have an 'Engineering Advisor' to the Govt. of India on the lines of the present 'Scientific Advisor'.

4. The Ministry of Science & Technology of Govt. of India can be renamed as Science, Technology & Engineering Ministry.

5. To engage Engineers in Government who have direct contact with the ground realities in the States and who come to the Centre for short stints to get an overall National View and also share their field experience from their respective States, there is need to have an 'Indian Engineering Service' which should be an All-India Service on the patterns of IAS, IPS & IFS. Creating provision of such a Service will not only send a signal about the importance of the role of Engineering/Engineers which the Government acknowledges but will also enhance inter-state cooperation in this vital field of Engineering. More talented Engineers from various states joining the proposed "Indian Engineering Service" will also help in National/Technological integration.

6. It will be necessary to include Planning and Policy making as an essential part of the Curricula / Examinations of the Engineering

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Education. Further, the Practising Engineers need to be suitably updated, at various stages, about the latest developments in the fields of Science / Technology / Engineering and consequent needs for changed skills.

7. Various Institutions and others should project the important role which Engineering/ Engineers are playing/have to play in development to educate the public. This will enhance the public image of engineering and will also result in better public support for related projects in addition to attracting better talent to the profession.

BOX 1

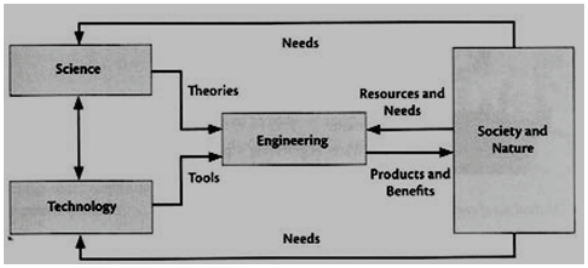
Changing Role of Engineering: Need for additional Inputs

Engineering is the profession that puts scientific knowledge to practical use. The word engineering comes from the Latin word 'ingeniare', which means to design or to create.

Engineers use principles of science to design structures, machines, and products of all kinds. They look for better ways to use existing resources and often develop new materials. Engineers have had a direct role in the creation of most of modern technology – the tools, materials, techniques, and power sources that make our lives easier.

The field of engineering includes a wide variety of activities. For example, engineering projects range from the construction of huge dams to the design of tiny electronic circuits. Engineers may help produce guided missiles, industrial robots, or artificial limbs for the physically handicapped. They develop complex scientific equipments to explore the reaches of outer space and the depths of the oceans. Engineers also plan our electric power and water supply systems, and do research to improve automobiles, television sets, and other consumer products. They work to reduce environmental pollution, increase the world's food supply and make transportation faster and safer.

Tony Marjoram and Yixin Zhong (UNESCO Report – 2010) diagrammatically depict the role Engineering plays (using 'Theories' from 'Science' and 'Tools' provided by 'Technology') to provide 'Products and Benefits' to 'Society and Nature' keeping in view the 'Resources and Needs'.



Tony Marjoram and Yixin Zhong (UNESCO Report – 2010) further elaborate that almost every area of human interest, activity and endeavour has a branch of engineering associated with it. They also provide an illustrative list of engineering branches mentioning various disciplines / sub-disciplines (See Box 2).

Unlike earlier times, when resources were in abundance and societal needs low, the current situation is altogether different. The current needs are of a much greater order of magnitude; environmental constraints are dangerously close to being breached; worldwide competition for scarce resources could create international tensions; and the freedom to power our way into the future by burning fossil fuels is denied.

Resolving these issues requires tremendous innovation and ingenuity by engineers, working alongside other technical and non-technical disciplines. It requires the engineer's ability to synthesize solutions and not simply their ability to analyze problems. Further, engineers need to develop the ability to take a systems view at a range of scales, from devices and products through to the large-scale delivery of infrastructure services.

Society today is making ever-greater demands on engineering, ranging from those caused by exploding urbanization and by the endemic poverty of a quarter of world's population in the face of overall global affluence, to the mounting concerns about availability of critical resources, the consequences of climate change and increasing natural and man-made disasters. This confronts engineering and society not only with unprecedented technical challenges, but also with a host of new ethical problems that demand the development of Global Engineering Ethics. How far should Engineering pursue the modifications of nature? What are Engineerings' roles and responsibilities in Society? How should Engineering address problems of equity in terms of the availability of resources and services of and between current and future generations? Should concerns about global warming take precedence over the urgent problem of poverty, or how can they be addressed together? To give a flavour of issues involving ethics an example concerning Environmental Ethics has been included in Box 3.

BOX 2

Illustrative List of Engineering Branches

Agricultural engineering

- o Engineering theory and applications in agriculture in such fields as farm machinery, power, bio-energy, farm structures and natural resource materials processing.

Chemical engineering

- o Analysis, synthesis and conversion of raw materials into usable commodities.
- o Biochemical engineering – biotechnological processes on an industrial scale.

Civil engineering

- o Design and construction of physical structures and infrastructure.
- o Coastal engineering – design and construction of coastline structures
- o Construction engineering – design, creation and management of constructed structures.
- o Geo-engineering – proposed Earth climate control to address global warming.
- o Geotechnical engineering – behaviour of earth materials and geology.

- Municipal and public works engineering – for water supply, sanitation, waste management, transportation and communication systems, hydrology.
- Ocean engineering – design and construction of offshore structures.
- Structural engineering – design of structures to support or resist loads.
- Earthquake engineering – behaviour of structures subject to seismic loading.
- Transportation engineering – efficient and safe transportation of people and goods.
- Traffic engineering – transportation and planning.
- Wind engineering – analysis of wind and its effects on the built environment.

Computer and systems engineering

- Research, design and development of computer, computer systems and devices.

Electrical engineering and electronic engineering

- Research, design and development of electrical systems and electronic devices.
- Power systems engineering – bringing electricity to people and industry.
- Signal processing – statistical analysis and production of signals, e.g. for mobile phones.

Environment engineering

- Engineering for environmental protection and enhancement.
- Water engineering – planning and development of water resources and hydrology.

Fire protection engineering

- Protecting people and environments from fire and smoke.

Genetic engineering

- Engineering at the bio-molecular level for genetic manipulation.

Industrial engineering

- Analysis, design, development and maintenance of industrial systems and processes.

Instrumentation engineering

- Design and development of instruments used to measure and control systems and processes.

Integrated engineering

- Generalist engineering field including civil, mechanical, electrical and chemical engineering.

Maintenance engineering and asset management

- Maintenance of equipment, physical assets and infrastructure.

Manufacturing engineering

- Research, design and planning of manufacturing systems and processes.
- Component engineering – assuring availability of parts in manufacturing processes.

Materials engineering

- Research, design, development and use of materials such as ceramics and nanoparticles.
- Ceramic engineering – theory and processing of oxide and non-oxide ceramics.
- Textile engineering – the manufacturing and processing of fabrics.

Mechanical engineering

- Research, design and development of physical or mechanical systems such as engines.
- Automotive engineering – design and construction of terrestrial vehicles.
- Aerospace engineering – design of aircraft, spacecraft and air vehicles.
- Biomechanical engineering – design of systems and devices such as artificial limbs.

Mechatronics

- o Combination of mechanical, electrical and software engineering for automation systems.

Medical and biomedical engineering

- o Increasing use of engineering and technology in medicine and the biological sciences in such areas as monitoring, artificial limbs, medical robotics.

Military engineering

- o Design and development of weapons and defence systems.

Mining engineering

- o Exploration, extraction and processing of raw materials from the earth.

Naval engineering and architecture

- o Research, design, construction and repair of marine vessels.

Nanotechnology and nanoengineering

- o New branch of engineering on the nanoscale.

Nuclear engineering

- o Research, design and development of nuclear processes and technology.

Production engineering

- o Research and design of production systems and processes related to manufacturing engineering,

Software engineering

- o Research, design and development of computer software systems and programming.

Sustainable engineering

- o Developing branch of engineering focusing on sustainability and climate change mitigation

Test Engineering

- o Engineering validation and verification of design, production and use of objects under test.

Transport Engineering

- o Engineering relating to roads, railways, waterways, ports, harbours, airports, gas transmission and distribution, pipelines and so on, and associated works.

Tribology

- o Study of interacting surfaces in relative motion including friction, lubrication and wear.

BOX 3

Environmental Ethics

Environmental ethics is a systematic account of the moral relations between human beings and their natural environment. It assumes that moral norms can and do govern human behaviour towards natural world. A theory of environmental ethics, then, must go on to explain what these norms are, and to whom or to what humans have responsibilities, and to show how these responsibilities are justified. Different theories of environmental ethics offer different answers to these questions:

- Some philosophers argue that our responsibilities to the natural environment are only indirect, that the responsibility to preserve resources, for example, is best understood in terms of the responsibilities that we owe to other humans. Anthropocentric (human centered) ethics holds that only human beings have moral value. Thus, although we may be said to have responsibilities regarding the natural world, we do not have direct responsibilities to the natural world.
- An extension of anthropocentric ethics occurs by considering future generations of human beings as objects of our moral responsibilities. Such an approach basically remains anthropocentric but it extends our responsibilities to include some of the humans who do not yet exist.
- Other philosophers argue that we also have direct responsibilities to natural objects other than human beings. This Non-anthropocentric ethics grants moral standing to such natural objects as animals and plants, and consequently requires further extensions and revisions of standard ethical principles.

- Further development of environmental ethics occurs by shifting from a focus on individual living things to focus on collections or 'wholes' such as species, populations, or ecosystems. Holistic ethics holds that we have moral responsibilities to collection of individual living things rather than (or in addition to) those individual living things who constitute the whole.

- The Ethics of Deep Ecology propagated by Arne Naess focuses on two ultimate norms. These norms are ultimate in the sense that they are not derived from any further or more basic principles or values. They are the point at which ethical justification ends. These two ultimate norms of deep ecology are self-realization and bio-centric equality. Self-realization is a process through which people come to understand themselves as existing in a thorough interconnectedness with the rest of nature. Bio-centric equality is the recognition that all organisms and beings are equally members of an interrelated whole and therefore has equal intrinsic worth.

BOX 4

Problems of Climate Change, Ecological Destruction and Other Related Issues

We are posed with unprecedented environmental challenges in the history of this planet today. The natural resources that sustain life on this planet – air, water, and soil – are being polluted or depleted at alarming rates. Human population growth is increasing exponentially and the prospects of continued degradation and depletion of natural resources multiply with this population growth. Toxic wastes that will plague future generations continue to accumulate worldwide. The world's wilderness areas, its forests, wetlands, mountains, and grasslands, are being developed, paved, drained, burned, and overgrazed out of existence. With destruction of the ozone layer and the potential for a greenhouse effect, human activity threatens the atmosphere and climate of the planet itself.

As the twenty-first century unfolds, it is becoming increasingly evident that the major problems of our time – the ecological destruction, climate change, poverty, energy, food security, financial security – cannot be understood / addressed in isolation. They are systemic problems, which mean they are all interconnected and interdependent. From the Systems point of view, the only viable solutions are those that are Sustainable.

The interconnected / interdependent problems of ecological destruction, climate change, poverty alleviation, population explosion and the like are staring at us. No single country or area can solve these problems in isolation and joint efforts on the part of world community are needed. Even though there is a growing realisation all over the world for joint efforts and some headway has also been made, but a concrete action plan is not yet available. To cite example, efforts for containing Global Warming / Climate Change have been made since 1988 when Inter Governmental Panel on Climate Change (IPCC) gave its First Report followed by several conferences / meetings but, a fully agreed Plan was still to emerge. The world is still divided in groups (e.g. Developed vs Developing blocks; Rich vs Poor countries) and necessary 'faith' among them is lacking.

In the meantime, signs of distress are clearly discernible. Melting of icecaps at poles, rising of sea levels, water and power shortages due to shrinking of glaciers affecting perennial water streams, and food crisis due to changing climate pattern are all clearly visible. Pollution of air, water, soil and even 'space' is increasing; low lands are getting submerged due to rise in sea levels; frequency of floods and storms has increased; and natural disasters have intensified. The problem calls for an urgent action.

To worsen the matter, attack by Coronavirus (Covid-19) since December 2019 has engulfed the whole world in extreme fear, uncertain future, and severe financial breakdown (primarily due to lockdowns imposed) besides infections and deaths. Brunt is being felt by one and all irrespective of their caste, creed or economic status. The Covid-19 started in December 2019 in Wuhan, China probably due to 'Bats' in their 'Wet Market' and till 31st July 2020 has infected about 17.0 million people and caused about 0.67 million deaths across 213 countries worldwide and the damage continues unabated. A strong message has gone down the world community that "None is safe, unless everyone is safe" in the words of U.N. Secretary General.

BOX 5

Major Challenges of the 21st Century

According to Sachs (2008), the defining challenge of the twenty-first century will be to face the reality that humanity shares a common fate on a crowded planet. This common fate will require new forms of global cooperation. While the challenge of the twentieth century was to handle a divided world, the challenge of the twenty-first century will be to handle an inter-dependent world.

In the last seventy-five years, most successful countries have gradually come to understand that their own citizens share a common fate, requiring the active role of government to ensure that every citizen has the chance and means to participate productively within the society, and to curb society's dangerous encroachments on the physical environment. Sachs (2008) observes that the challenges of sustainable development – protecting the environment, stabilizing the world population, narrowing the gaps between the rich and the poor, and ending extreme poverty – will need global cooperation. To find the way peacefully through these difficulties, we will have to learn, on a global scale, the same core lessons that successful societies have gradually and grudgingly learnt within their own national borders.

Four goals have been suggested by Sachs (2008) to overcome these challenges of sustainable development:

- Sustainable systems of energy, land, and resource use that avert the most dangerous trends of climate change, species extinction, and destruction of ecosystems.
- Stabilization of the world population at eight billion or below by 2050 through a voluntary reduction of fertility rates.
- The end of extreme poverty by 2025 and improved economic security within the rich countries as well.
- A new approach to global problem solving based on cooperation among nations and the dynamism and creativity of the non-governmental sector.

Attaining these goals on a global scale may seem impossible. Yet there is nothing inherent in global politics, technology, or the sheer availability of resources on the planet to prevent us from doing so. We need agreements at the global level and attitudes throughout the world that are compatible with meeting the global challenges.

BOX 6

United Nations – Sustainable Development Goals (SDGs)

The Sustainable Development Goals (SDGs), officially known as Transforming our World: the 2030 Agenda for Sustainable Development are an intergovernmental set of Seventeen Goals and are:

1. No Poverty - End poverty in all its forms everywhere.
2. Zero Hunger - End hunger, achieve food security and improved nutrition and promote sustainable agriculture.
3. Good Health and Well-being - Ensure healthy lives and promote well-being for all at all ages.
4. Quality Education - Ensure inclusive and equitable quality education and promote lifelong learning opportunities for all.
5. Gender Equality - Achieve gender equality and empower all women and girls.

6. Clean Water and Sanitation - Ensure availability and sustainable management of water and sanitation for all.

7. Affordable and Clean Energy - Ensure access to affordable, reliable, sustainable and clean energy for all.

8. Decent Work and Economic Growth - Promote sustained, inclusive and sustainable economic growth, full and productive employment and decent work for all.

9. Industry, Innovation and Infrastructure - Build resilient infrastructure, promote inclusive and sustainable industrialization and foster innovation .

10. Reduced Inequalities - Reduce inequality within and among countries.

11. Sustainable Cities and Communities - Make cities and human settlements inclusive, safe, resilient and sustainable.

12. Responsible Consumption and Production - Ensure sustainable consumption and production patterns.

13. Climate Action - Take urgent action to combat climate change and its impacts.

14. Life Below Water - Conserve and sustainably use the oceans, seas and marine resources for sustainable development.

15. Life on Land - Protect, restore and promote sustainable use of terrestrial ecosystems, sustainably manage forests, combat desertification, and halt and reverse land degradation and halt biodiversity loss.

16. Peace, Justice and Strong Institutions - Promote peaceful and inclusive societies for sustainable development provide access to justice for all and build effective, accountable and inclusive institutions at all levels.

17. Partnerships for the Goals - Strengthen the means of implementation and revitalize the global partnership for sustainable development.

BOX 7

Five E's of Sustainable Development

If one is asked to choose parameters which can help an individual to perform all his/her actions/activities, on a sustainable basis, in the best possible manner, the following Five E's could be listed:

i) Efficiency

ii) Effectiveness

iii) Ethics: Essential for sustainable performance

iv) Environment: Be in tune; Don't damage; Improve, if possible

v) Evolution: Create positive impact on the value structure.

Efficiency covers all activities, which make actions efficient and will, interalia, include efficient time management, good physical and mental health, possession of adequate knowledge and skills, will to do the job, positive attitude, doing things right the first time, low stress levels, etc.

Effectiveness will mean that the actions result in achieving useful goals for which it will be essential to have necessary vision, broad idea of goals to be achieved, systems to be followed to reach the goals, necessary co-ordination/co-operation with other individuals/organizations, conscious realization of one's capacity/capability levels etc.

Ethics is essential for sustainable development and performance. It also helps in arriving at solutions, which are more equitable (concern for Equity). It reduces stress levels, as ethical paths can be very clearly charted as against the paths which are followed for achieving the goals through unethical means.

Environment has to be seen in a broader context and may include physical environment, working environment, political environment, financial environment and the like. Activities have to be performed keeping these in mind, lest they trigger reactions which may be difficult to control. Further, actions should not damage the environment rather; improve it to the extent possible.

Actions must support the process of evolution and development in the positive direction for all those connected with the activities. Decline in human values can be detrimental to society.

For better performance on a sustainable basis these parameters, i.e., the Five 'Es' are equally relevant to a Group of Individuals (Teams), Activities, Systems, Organizations and even the Nations. Efforts should be directed to continuously improve upon them.

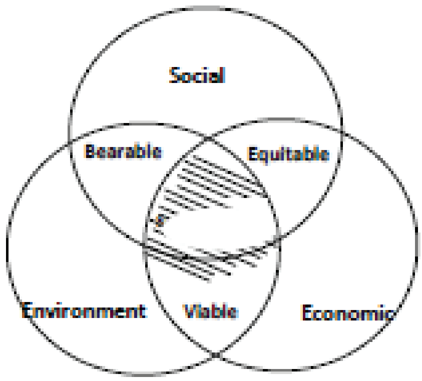
BOX 8

Sustainable Development – Brundtland Commission

The Brundtland Commission (UN) in their Report (1987) defined sustainable development as "development that meets the needs of the present, without compromising the ability of future generations to meet their own needs". This broad definition however needs further elaboration as detailed below:

- A triple bottom line perspective, that considers environmental, economic and social aspects
- A time dimension, which incorporates short term to long term, and considers impacts along the lifecycle, including impact on future generations
- A resource context with respect to scarcity, over-abundance, or potential to disrupt resource availability in the future.

Sustainable development will be possible only when it is recognized that economic growth, social welfare and environmental issues are linked and have to be addressed together, rather than in a fragmented way as practiced currently. The figure below indicates the relationship among the three pillars of sustainability viz., economic, environmental, and social aspects.



Three Pillars of Sustainability

BOX 9

Sustainable Economics / Ecological Economics

In recent decades an alternative to classical market based economics has emerged and we can call it "sustainable economics". It offers a different way to think economics in the light of our current environmental challenges and apparent failure of classical market economics to meet these challenges. Sustainable economics appeals to the same philosophical values for its justification – utility, freedom, equality – as does classical market economics. It claims, however, to better promote these values, given the current and future environmental reality. The following summarizes the current and future challenges in this regard:

a) A large percentage of the world population today lives in abject poverty. One quarter of the world's population lives in industrialized countries and consumes 80% of the world's goods. The world would, therefore, require significant economic growth during the next few decades just to meet the basic needs of the other 75% of the planet's population.

b) The world's population during the next 50 years is likely to double and the economic activity to meet the basic needs of the population will need to increase significantly.

c) Since the resources for all the economic activity are the natural resources of the earth itself and since the world's environment is already under stress from the current economic activity, the future looks bleak.

Thus, given these realities, we must create an economic system that can provide for the worlds' population without destroying the environment in the process.

Classical economics is governed by the law of supply and demand and this model of economic activity is linear: resources enter at one end, allocation decisions are made to produce various goods, and these are then distributed at the other end, in a competitive market place. Sustainable economics is particularly concerned with the rate at which resources flow through the economy. It recognizes that all the factors that go into production – natural resources, capital, and labour – ultimately originate in the productive capacity of the earth. The sustainable economic system will be that which uses resources only at a rate that can be sustained over the long term, and recycles or uses both the by-product of the production process and products itself.

The "Sustainable Economics", as defined above, can also be termed "Ecological Economics" as it has the following features:

i. It is a form of economic thought with which the environment movement, in its mainstream, is most comfortable

ii. Ecological Economics not only shifts the focus from micro to macro but also from a very short time period to 'deep' time

iii. It complements the relational and synergistic realities of ecology.

iv. Such an economics also incorporates an ethical and visionary dimension.

BOX 10

Lessons on Sustainability from the Ecosystems

How to achieve the goal of sustainable development is a major problem staring at us. The authors (Capra and Luisi-2014) suggest that to achieve sustainable human communities we can model them after nature's ecosystems which are sustainable communities of plants, animals and microorganisms. Further, the sustainable human community be designed in such a manner that its way of life, businesses, economy, physical structures, and technologies do not interfere with nature's inherent ability to sustain life.

In our endeavour to understand how nature sustains life, we need to understand the organisational principles that ecosystems have evolved to sustain the web of life. Some of these are discussed below along with the lessons for the human community:

i. The first of these principles is interdependence. All members of an ecological community are interconnected in a vast and intricate network of relationships, the web of life. The success of the whole community depends on the success of its individual members, while the success of each member depends on the success of the community as a whole.

   A sustainable human community has to be conscious of the multiple relationships among its members, as well as the relationship between the community as a whole and its natural and social environment.

ii. Being an open system, all organisms in an ecosystem produce wastes, but what is waste for one species is food for another, so that the ecosystem as a whole remains without solid wastes. Communities of organisms have evolved in this way over billions of years, continually using and recycling the same molecules of minerals, water and air.

   Lesson for the human communities here is obvious. Sustainable patterns of production and consumption need to be cyclical, imitating the cyclical processes of nature.

iii. Solar energy, transformed into chemical energy by the photosynthesis of green plants, is the primary source of energy driving the ecological cycles.

   For sustainable human communities the solar energy in its many forms – sunlight for solar heating, photovoltaic electricity, wind and hydropower, biomass etc. – is the only kind of energy that is renewable, economically efficient, and environmentally benign.

iv. The cyclical exchanges of energy and resources in an ecosystem are sustained by pervasive cooperation. Partnership is an essential characteristic of sustainable ecological communities.

Sustainability is not an individual property but a property of an entire web of relationships. It always involves a whole community.

v. The flexibility of an ecosystem is a consequence of its multiple feedback loops, which tend to bring the system back into balance whenever there is deviation from the norm due to changing environmental conditions. All ecological fluctuations take place between tolerance limits. There is always the danger that the whole system will collapse when a fluctuation goes beyond those limits and the system can no longer compensate for it.

In human communities, ethnic and cultural diversity may play the same role. Diversity means many different relationships, many different approaches to the same problem. A diverse community is a resilient community, capable of adaption to changing situations. However, diversity is a strategic advantage only if there is a truly interconnected community, sustained by a web of relationships.

BOX 11

Shift in Norms for Values / Thinking – More Integrative Approach

During the Industrial Revolution of the seventeenth century, values were separated from facts, and ever since that time scientists tends to believe that scientific facts are independent of our values. Thomas Kuhn exposed the fallacy of that belief by showing that scientific facts emerge out of an entire constellation of human perceptions, values and actions – out of a paradigm – from which they cannot be separated. Although much of our detailed research may not depend explicitly on our value system, the larger paradigm within which this research is pursued will never be value-free. As scientists, therefore, we are responsible for our research not only intellectually but also morally (Ref.: Capra & Luisi – 2014).

Further, the broader paradigm shift also needs corresponding changes of values, and here it is interesting to note a striking connection between the change of thinking and change of values. Both of them may be seen as a shift from self-assertion to integration. These two tendencies – the self assertive and the integrative – are both essential aspects of all living systems. Neither of them is intrinsically good or bad. What is good, or healthy, is a dynamic balance; what is bad, or unhealthy, is imbalance – overemphasis on one tendency and neglect of the other.

Thinking		Values	
Self Assertive	Integrative	Self Assertive	Integrative
Rational	Intuitive	Expansion	Conservation
Analysis	Synthesis	Competition	Cooperation
Reductionist	Holistic	Quantity	Quality
Linear	Non-Linear	Domination	Partnership

When we look at our modern industrial culture, we see that we have overemphasised the self assertive and neglected the integrative tendencies both in our Thinking and in Value systems. (Ref.: Capra & Luisi – 2014)

BOX 12

Market/Social/Spiritual Values

Value Chain Analysis for Market Values, Social Values, and Spiritual Values and the driving forces behind them are given below (Subhash Sharma – 2007). It can be seen from the same that global problems of our inter-dependent world cannot be solved through an approach where 'self-interest', i.e., market driven approach, is predominant. Higher values are the need of the hour.

Nature of Values	Illustrative Phrases & Expressions of the Value Chain	Driving Force
Market Values	Competition, Efficiency, Profitability, Survival of the fittest, Downsizing, Economic Value Addition (EVA), etc.	Self-interest
Social Values	Co-operation, Justice, Equity, Human rights, Gender equality, Social harmony, Pluralism, Workplace diversity, Empowerment of the Weakest, Bio-diversity and other Environmental concerns, etc.	Enlightened self-interest
Spiritual Values	Symbiosis, Helping others, Joy, Bliss & Peace, Beauty, Goodness & Truth, Symphony & Harmony, Survival of all & development of all, etc.	Enlightened collective interest

BOX 13

Gandhian Engineering

Dr R A Mashelkar in his Lifetime Contribution Award Lecture 2012 (INAE – April 2013) mentions two tenets propounded by Mahatma Gandhi:

(i) 'I would prize every invention of science made for the benefit of all'.

(ii) 'Earth provides enough to satisfy every man's need but not every man's greed'.

He further elaborates that the first tenet refers to affordability and the second tenet to sustainability.

He explains that industrial enterprises strive for getting more (performance) from less (resource) for more (profit) but the Gandhian Engineering has a different message. It means getting more (performance) from less (resource) for more (people), not just for more (profit).

Getting More from Less for More (MLM) strategy forces us to measure an opportunity by the ends of innovation – what people actually get to enjoy – as opposed to just an increase in their means. In important ways, this rationale invokes a return to the traditional case for innovation – its ability to produce breakthrough improvements in the quality of life – alongside the usual objective of competitiveness.

The objectives of MLM type of innovations would not be just to produce low performance, cheap, knock-off versions of rich country technologies so that they can be marketed to poor people. Rather, the objective is to harness sophisticated science and technology know-how to invent, design, produce and distribute high performance technologies at prices that can be afforded by majority of people.

Gandhian Engineering is all about getting more from less for more people – this MLM way of innovation is anchored on the solid foundation of affordability and sustainability. It will create a more equitable society and will also help us in designing a sustainable future.

BOX 14

Growth / Progress / Development – Changing Norms

Most countries use Gross Domestic Product (GDP) to measure the standard of living. Economists, policymakers, international development agencies and even the media use it as an indicator of the economic health of a nation. The advantages offered by GDP are that it is widely and frequently used and its data requirements are readily available. Since the definition is common amongst countries, consistent comparisons can be made between and among them.

The countries at the top of the GDP list take the lead in terms of total economic activity taking place within their boundaries. However, it does not necessarily mean that their citizens are better off than the rest of the world in terms of overall well being. For example, a high level of manufacturing and industry related activities (with consequent high toxic emissions) may contribute to a higher GDP but the people will suffer living and working in a polluted environment. Further, certain activities that have a negative impact on the people's well being could end up being recorded as positive contributions to GDP. Take for instance, crime. Rising criminal activities can increase the country's GDP through greater expenditures towards maintaining law and order (e.g. hiring of additional police force, purchase of guns, prisons, etc.). The GDP is also criticized because it does not take into consideration other aspects that define human well being like life expectancy and educational attainment.

It is for these reasons that alternative ways of measuring standard of living have emerged. One of these is the Human Development Index (HDI) developed by the United Nations. The HDI takes into account the GDP and adds more factors to measure other aspects of human development: knowledge, longevity, and decent standard of living. HDI values range from 0 to 1. The HDI, however, has its own share of critics. Some point out that it is difficult to chart a country's growth using HDI. There are also others who say that HDI does not capture the moral and spiritual aspects of human development.

Bhutan has begun to use Gross National Happiness (GNH) as a broader and more nuanced measure of national progress than GDP. Bhutan's audacious solution is to build its society from the ground up using what it calls the "four pillars" of GNH: sustainable economic development, conservation of environment, preservation of culture, and good governance. Bhutan's happiness experiment has captured the fancy of economist and politicians from Brazil to Britain, Tokyo to Taiwan, who are looking for a new path to free-market prosperity – one that doesn't do so much damage to the environment, social equity and family life. Joseph Stiglitz, a Nobel Prize-winning economist has become world's leading advocate for developing better measures of national well being and he leads an influential Commission funded by the French Government for the purpose. Canadian researchers have created a composite of 64 existing statistics, including work hours and incidence of violent crime, that are considered proxies for various components of well being. (Ref.: Time Magazine – 22nd October 2012)

The above discussion clearly highlights that even though adequate tools to measure growth/progress/development may not be available but economic growth alone is not enough. Indian planners are emphasizing 'inclusive growth' which broadly takes into account the aspects of poverty reduction and also of reducing disparities. Our growth/progress/development model has to necessarily take into account the following three issues/areas besides the economic growth:

- Sustainable Development
- Climate Change: Mitigation and adaptation
- Poverty Reduction / Inclusive Growth

These three issues are fundamentally engineering issues and the engineering/engineers have a paramount responsibility and role to play in these areas.

BOX 15

Technology Foresight

Futures studies have been with us for a long time, but the term 'foresight' has only come into wide use in recent years. A striking development in the last decade of the twentieth century was the growing prominence of large scale foresight exercises conducted at national and international levels. This trend was amplified in the new millennium. These exercises, usually funded by governments and intended to provide insights for innovation policy, priorities for research and development funding, and the like, frequently went by the name 'Technology Foresight'.

Several factors converged to foreground foresight. First was the need to prioritize research budgets – choices needed to be made as to where to invest, as governments were not able to continue funding across the whole spectrum. Second, there were growing concerns about the implications of science and technology and how to shape development so that new technologies could prove more socially and environmentally beneficial. A third set of factors concern innovation. Innovation has come to be recognized as a key element in competitiveness, national performance and achieving socio-economic objectives.

One lesson learned early on during foresight exercises was that it was important to bring together expertise in social affairs, business management, financial issues and policy together with expertise possessed by scientists and engineers. What was proved to be at a premium is the capability to possess (and share) highly specialized knowledge and also to be able to relate this understanding to the issues raised in a wide range of other fields: people with T-shaped profiles (people with in depth knowledge of their own domain as well as competence in a much broader spectrum of managerial, interpersonal and other skills). Additionally, foresight required open minded people. (Ref.: UNESCO Report - 2010).

BOX 16

Problem Solving Approach of the Technology Foresight Forum

1. The Members of Forum (Group in short) during the initial meetings decided the line of action to be followed for effectively and speedily handling this daunting task. Even though the Forum will be working on the various National Challenges on a continuous basis it was thought prudent to select some priority areas for directed attention in the first instance. Since the domain of National Challenges is very wide and keeps on changing with time, it was felt that use of expertise of domain 'experts' may be difficult and may cause avoidable delays in formulating recommendations. It was, therefore, the view of the Group to make use of the available data (published literature, reports, media information, INAE literature, data from internet, etc.) and contacts/ knowledge of the Group Members with occasional interaction with the experts. The option to invite Specialists as required and/or conduct Workshops as found necessary was kept open.

2. To achieve commonality of approach and to have a common understanding of the various technical terms/issues, some of the areas, as discussed by the Group, are mentioned below:

   - Solutions for addressing the National Challenges have to keep in focus issues concerning Sustainable Development, Climate Change, and Poverty-reduction / Inclusive Growth
   - Boundaries between Science, Technology, and Engineering have to be made more explicit. This is all the more necessary because of the growing role of Engineering and its close interface with society/nature
   - For Technology Foresight exercises to be more useful / effective it was necessary to bring together expertise in social affairs, business management, financial issues, and policy with the scientific, technological, and engineering issues
   - Too much emphasis on the authenticity of Data / Source was not a practical reality as the challenge was many a times to venture into new areas not only Scientific / Technological / Engineering but also areas concerning Social affairs / Business management / Finance / Policy and their inter-relationships

- Dimensions of Project Management were becoming more and more complex and diverse and needed special attention. Our poor track record in Project Implementation amply testified this need
- Expanding definitions of Growth / Progress / Development need to be taken into account (Gross Domestic Product – Human Development Index – Gross National Happiness)
- Ethical issues especially concerning the environment needed to be addressed
- Innovations needed to be such so as to achieve More from Less for More (MLM) people for sustainability and equity
- Role of technology was not only to be seen from the point of view of achieving the desired objectives but also from the point of view of its consequences
- Many of the challenges / risks have global dimensions and this had to be kept in view
- Necessary inputs for Skill development and Training were needed to match the futuristic technologies. Quality of engineering education especially for Tier II, III & IV colleges needed special inputs
- Policy frame work will have to be in place to improve the 'image' and 'role' of Engineering to make it more effective especially in tackling social and economic development and for provision of commensurate infrastructure.

BOX 17

Society 5.0 – Making it Human Centric

(a) Classification

1.0 Hunting society

2.0 Agrarian society

3.0 Industrial society

4.0 Information Society (Current stage)

5.0 Super Smart Society (Society of Future).

(b) There are countless directions in which Society will advance through technological developments. While technology could bring about improvements such as high standards of living and greater convenience, it could have negative effects too, such as impact on unemployment, growing disparity and unequal distribution of wealth and information. We must consider what kind of Society we work to create rather than trying to foresee what kind of Society it will be.

(c) Some thinking in Japan: Five Walls to Break Through in Society for making it Human Centric

- The wall of Ministries and Agencies
- The wall of Legal System
- The wall of Technologies
- The wall of Human Reserves
- Social implications, ethics and social acceptance by all stake holders.

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Cyber Security for Sustainable Development

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ABSTRACT

The high-volume use of Internet technologies for applications such as e-Governance, e-Commerce, e-Banking, digital payments, mobile services / applications, smart cities etc., has mandated security of related devices including computers, mobile phones and networks. It is very obvious for the IT sector to be concerned about the security issues as in the recent times we have seen the devastating cyber-attacks causing massive damage across the world.

The growing importance of Cloud, IoT and Mobile applications and use of social media in day to day applications has resulted in the wider opportunity for the cyber criminals, increasing the threat surface. As our Nation is transforming to Digital Economy, through various initiatives such as Digital India, Digilocker, Aadhar, m-Payments, Smart Cities, etc., we need a holistic approach in Cyber Security.

Research and Developments efforts in Cyber Security should be based on the requirements of user agencies and global threat scenario. Products / Solutions should undergo testing / evaluation and certification for assurance on quality of solutions for sustainable development.

INTRODUCTION

In the current era, dependency on the internet has become important for functioning of modern society as well as for its further development. So it is not surprise that there are immense activities in cyberspace, which bring profits straight away, while others cause tremendous loss. Modern society has the responsibility to handle new challenges such as the need to protect critical points of cyber vulnerabilities in the infrastructure.

Based on the statistics of the attacks that have been seen in recent time, we can see that most agencies attacked are in military, energy, financial and critical infrastructure installations. From these attack scenarios and literature, there is need to develop common approaches and methodologies which will set the base for systematic planning that would eventually lead to building sustainable protection against cyber attacks.

Cyber Security economics addresses the issues of safeguarding Information and Communications Technology (ICT) applications, which are designed to facilitate the economic activities to get disrupted, eventually costing the companies and countries huge amount of money and disturbing the economic and financial activities around the globe [ICT & Sustainable Development Goals (SDGs) report, 2015]. The report addresses the role of ICT in achieving SDGs that is introduced by the United Nations (UN) for its members to achieve SDGs that are planned to be implemented within 2030. Moreover, the report points out the concerns in the areas of potential downsides of ICT-based sustainable development. Sociologist Robert Putnam assumes that online communications will lead to real human communities heading to a decline in human interactions, trust, and sociality; phenomenon which will lead to a called bowling alone. As it is expected to displace human endeavors to the point of creating mass unemployment and economic unrest. This point faces lot of arguments from various facts of the society, however the crucial fact in Journal of the Knowledge Economy is that with proper public policies, technological advances develop and wellbeing will lead to considerable positive externalities of digital technology that has shaped the digital economy world over. But, the negative externalities associated with advances of these technologies are the Cyber Security negative externalities and the mismatch of the human skills to optimize the digital dividends generated in terms of economic growth contribution through the usage of this technology to create economic values.

SUSTAINABLE DEVELOPMENT

The consequences of this short-term approach to Cyber Security appear regularly in the media around the world. The most critical of computer hardware was for decades vulnerable to acute security weaknesses; multiple governments and organizations have had sensitive consumer personal data and proprietary corporate information compromised; and industrial control systems and other critical infrastructure have been unlawfully accessed by criminals and nation state actors. More recently, poorly secured IoT has become a force multiplier for malicious actors who continue to expand the scale and impact of distributed denial-of-service (DDoS) attacks.

Stakeholder misconceptions about market interest in security capabilities exacerbate the results of society's suboptimal choices. For example, a recent study of communications service providers (e.g., telecommunications carriers) and purchasers (e.g., enterprises such as corporations) found that enterprises were willing to pay a 15 percent premium to support compliance with secure internet routing practices (the process of transmitting packets over the internet). The same study revealed that service providers underestimated the value their customers place on security and highlighted that providers' security posture is a characteristic to distinguish competitors. This disconnect highlights the need for additional analysis of enterprise and consumer willingness to pay more for better security, and not just in the connectivity and transmission context. At the same time, it begs the question of whether or not they should have to. Security is a fact of doing business. Doing it right should not always have to cost enterprise customers and individual consumers more. But to date, doing it wrong has – perhaps most significantly in risking public trust in ICTs.

Together with these misperceptions, current market incentives do not support adequate Cyber Security investment and funding. Often, the organizational victim of malicious cyber activity could have avoided or reduced its impact by investing in Cyber Security during procurement, employee training, and network design and management, to name but a few effective approaches. "When market incentives encourage manufacturers to feature security innovations as a balanced complement to functionality and performance, adoption of tools and processes that result in highly secure products is easier to justify." The government, institutional investors, and other relevant stakeholders must emphasize that investment in Cyber Security in the early stage of a product or service development, as well as in network architecture and management, are more cost effective than attempting to bolt it on just before going to market, or failing to address it at all.

Inadequate Cyber Security practices by governments and non-governmental organizations (NGOs) present a particularly pressing concern given the critical roles of such organizations in the ecosystem and in influencing public perceptions of trust. Insecure networks risk not only is becoming part of the problem, but also the target. Criminals and nation states can take advantage of vulnerabilities in networks to; for example, build a botnet, which can be directed at any number of internet-connected devices, from home refrigerators to smart factories to medical devices, regardless of these targets' proximity. Given challenges in attributing cyber activity, poor Cyber Security practices by governments in particular can potentially exacerbate the consequences and further erode public trust in ICTs - if, for example, a government were to take action abroad in response to malicious activity enabled by a poorly configured system that has been compromised by actors operating in a third country. And yet, due to the increasingly prevalent role ICTs play in all aspects of society, the same concerns about unintended consequences could be said for almost all stakeholders' Cyber Security actions. Furthermore, the effects of the current unsustainable approach to ICT security threaten not only strong digital economies, but also nascent ones. Failure to trust and adopt ICTs, due in part to their insecurity, risks countries realizing the benefits these emerging digital populations could experience in the modern economy. At the same time, authoritarian regimes exploit insecure ICTs and their effects to develop legal systems that undermine privacy in the name of security. These governmental policies can take many forms, from unchecked access to communications' metadata and content to data localization and source code requirements, any one of which can undermine security and privacy and thereby public trust in information and communications technologies. Stakeholders' failure to address ICT security challenges throughout the ecosystem may cost emerging digital economies the opportunity to see the true economic and social benefits interconnection can bring.

Even well intentioned regulatory efforts that directly and indirectly improve Cyber Security, e.g., the General Data Protection Regulation (GDPR), can fall short. Although the results of these efforts are not yet calculable, this varied regulatory landscape presents challenges for organizations operating internationally and highlights the limitations national and regional regulatory regimes face in truly enhancing Cyber Security on a global scale.

These shortfalls and limitations evidence a need for a more holistic approach to ICT security and privacy. Public and private organizations and consumers should collaborate to identify best practices and frameworks that transcend boundaries, national laws, and cultures to create a cohesive ICT security agenda to sustain the modern economy into the future. An enduring approach should view the security of ICTs and associated privacy enhancements as critical to their sustainability, and thus the sustainability of the modern economy. As Palo Alto Networks CEO, Mark McLaughlin, has cautioned, "The life of the digital age is literally at risk if we don't advance security prevention."

CYBER SECURITY

Cyber Security refers to the technologies and processes designed to protect computers, networks and data from unauthorized access, vulnerabilities and attacks delivered via the Internet by cyber criminals. Cyber Security is important for network, data and application security.

Cyber Security standards are security standards which enable organizations to practice safe security techniques to minimize the number of successful cyber security attacks.

Communication Security is protecting organization communication media, technology and content

Network Security is the protection of networking components, connection and content.

Information Security is the protection of information and its critical elements, including the systems and hardware that use, store or transit that information.

- Identify Theft – Cyber Security awareness
- Easy access communication – at the cost of personnel safety and security
- Digital transactions / Digital Empowered Society
- Personnel Identification :
  - Name / Phone no.
  - Email ID/ DOB/ Address
  - Personal accounts / Aadhar
  - Voter ID/ Credit and Debit Cards

- Passport Details
- Iris Scan/ Finger Prints
- Voice Sample, etc.,

❖ Personnel Information – Malware – Email / SMS / Whatsapp link

❖ Malware – Viruses, Spyware, Root kits, Remote access tools

❖ Credit card/ Debit card/ Smart pay network (shopping, etc.,) can be read through RFID devices without physical contact.

❖ Messages - Job offers, Cash Prize, lottery through email/ Whatsapp/ SMS mails through Original logos.

❖ Personnel Sensitive information through like Banking details etc.,

❖ Shopping portals, e-commerce sites/ online banking details.

❖ Information through computer servers/ access through ports, weak password vulnerability for attack by criminals.

❖ Submitting false – application for loans/credit cards withdrawal from Banks.

❖ Fake Online accounts in Social Media defame in social media network sites.

❖ Forgery of documents, new phone connection.

❖ PAN Card/ Medical Insurance Claims/ Fraudulent Tax Returns

❖ Driving Licenses/Passport/Aadhar etc.,

VIRUSES – Android Banker Trojan

PRECAUTIONS

❖ Two Factor authentication

❖ Credit / Debit Card PINS – Onlookers

❖ Anti-Virus updates

❖ Encrypt internet connection – save from malware

❖ Regularly check – online accounts/Social networking sites

❖ Limit - Personal Information

❖ Online Shopping – Secure Payment Gateways

❖ Send password protected documents over the internet

CYBER CRIME

The former descriptions were "computer crime", "computer-related crime" or "crime by computer". With the pervasion of digital technology, some new terms like "high-technology" or "information-age" crime were added to the definition. Also, Internet brought other new terms, like "cyber crime" and "net crime.

Other forms include "digital", "electronic", "virtual", "IT", "high-tech" and "technology-enable" crime.

Cyber Crimes Include

- Illegal access.
- Illegal Interception.
- System Interference.
- Data Interference.
- Misuse of devices.
- Fraud.

Cyber Protection

- Read privacy policy carefully when you submit the data through internet.
- Encryption: lots of website uses SSL (secure socket layer) to encrypt a data.
- Disable remote connectivity.

Advantages of Cyber Security:

- It will defend from hacks and virus.
- The application of cyber security used in our PC needs update every week.
- The security developers will update their database every week once. Hence the new virus also deleted.

Safety tips

- Use antivirus software.
- Insert firewalls, pop up blocker.
- Uninstall unnecessary software.
- Maintain backup.
- Check security settings.
- Use secure connection.
- Open attachments carefully.
- Use strong passwords; don't give personal information unless required.

CONCLUSION

1. To evolve a model for identifying cyber security problem statements meeting the user requirements.
2. Evolving a model for transitioning of successful R&D results to widespread deployable solutions (commercial / open source).
3. To create indigenous solutions and domain wise capabilities across different verticals of cyber security.
4. Identifying the infrastructure (test beds) and datasets requirements for effectively carrying out functionality, security & scalability testing of the developed solutions.
5. To build industry capable talent, start-up community and entrepreneurial ecosystem for cyber security.
6. To generate awareness on Cyber Security, Cyber Crime and legal aspects of Cyber Security.

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A Space Strategy for India

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BACKGROUND

There is no doubt that India has achieved a great deal in space. Despite smaller budgets, the development driven agenda and civilian focus of the Indian Space Programme, has yielded significant benefits. Over the last five years, there has also been an increasing trend towards the use of space for military purposes. An ASAT test in 2019 reiterated India's resolve to safeguard vital security interests involving space. The launch of Chandrayaan missions to the moon and the Mangalyan mission to Mars illustrate Indian pursuits of new knowledge. The formal approval of a human space flight programme in 2018 also signaled Indian political aspirations towards achieving "great power status" on the global stage.

Though these are welcome developments, concerns remain whether these responses are adequate to cope with the challenges posed by the emerging world space order. The growing rivalry between China and the US has a major space component. This competition involves the economic, political, military and the knowledge components of what is now being termed as "Space Power". A dispassionate appraisal of India's space capabilities in the context of these challenges is needed for the charting of an appropriate space strategy for India. This paper tries to provide a framework for arriving at such a strategy. While drawing upon an earlier study that looked at the military and economic dimensions of the challenges, this paper also brings in the knowledge and geo-political dimensions for the formulation of a suitable Indian response to the global challenges in space.[1]

THE EVOLUTION OF THE WORLD SPACE ORDER

The Sanctuary Regime (1957 to 1984)

The period between the launch of Sputnik in 1957 till the announcement of the Strategic Defence Initiative (SDI) by President Reagan in 1984 can be characterized as the "Sanctuary Regime in Space". The missiles that delivered nuclear weapons also made possible the launching of satellites that could perform a variety of functions from their vantage point in space. Reconnaissance, Communications, Navigation and Weather services were the early applications that diffused rapidly from the military into the civilian sector. The C4ISR functions[2] performed by the early military satellites played a major role in stabilizing the relationship between the two superpowers.

Though both superpowers tested nuclear weapons in space and developed Space Weapons, their mutual need to promote nuclear stability made them restrict their actions to R&D and limited testing. They cemented their commitment to maintaining the space environment as a regime free of weapons through several bilateral and multilateral agreements that linked the nuclear

1. S. Chandrashekar. Space, War and Security – A Strategy for India. NIAS Report No. 36-2015. Bangalore: International Strategic and Security Studies Programme, National Institute of Advanced Studies, December 2015.
2. Command, Control, Communications, Computers, Intelligence, Surveillance & Reconnaissance.

weapons regime with the emerging space regime[3]. The competition between the two superpowers also resulted in huge human flight programmes that culminated in the Apollo landings on the moon. This period also saw major advances in the exploration of the solar system, astronomy and earth sciences using satellites.

The diffusion of military space technologies into the civilian sector created huge opportunities for economic development. Communications satellites, remote sensing, weather services and navigation become huge industries with very large value chains and growth prospects. Many countries became beneficiaries of the sanctuary regime as technology and applications diffused into the global economic system.

Space as Contested Ground (1985 to 2000)

The period between the initiation of President Reagan's Strategic Defensive Initiative (SDI) in 1984 and 2000 saw the transformation of the sanctuary regime in space into contested ground. Though the SDI promise of a "perfect shield against ballistic missile attack" was never fulfilled, it triggered a relook at the role of space weapons. The breakup of the Soviet Union in 1991-1992 also had a profound impact on the world space order.

The first Gulf War saw a real-life demonstration of how US Space Power was used to win a conventional war. US space based C4ISR and Early Warning satellites directly linked space with the waging and winning of a conventional war. These developments reinforced the connections between Space and the waging and winning of a conventional war. It also brought into visible focus the possible role that BMD weapons would have on such wars. Space therefore became inextricably linked not only to nuclear war and nuclear deterrence but also to conventional war and conventional deterrence.

3. Strategic Arms Limitation Treaty (SALT) and the Anti-Ballistic Missile (ABM) Treaty were the early treaties for ensuring strategic nuclear stability between the superpowers. They also recognized the role of space assets for preserving status quo.

The accident to the US Space Shuttle Challenger along with the grounding of other US launchers led to an increasing dependence of US satellite manufacturers on Russian and Chinese launch vehicles. The US Chinese bonhomie directed against the Soviet Union started breaking down as China's investments in space started posing a direct threat to US commercial and trade interests. The period from 1991 onwards till the early part of the 21st century also witnessed the military and commercial domination of space by the United States. US communications, remote sensing and weather satellites were state-of-art. The US GPS navigation system became a global standard. NASA missions to the planets of the solar system, its Hubble and other telescopes set the standards for creating new knowledge. The integration of space services into daily mainstream life became a common feature across countries.

The Era of China US Rivalry & Space Power (2000 to 2020)

The dawn of the 21st Century saw China emerge as a major challenger to the US in the space domain. China's human space flight programme initiated in the 1990s, saw fruition in the first two decades of the 21st Century. As the US closed the Space shuttle programme, it needed Russian help for maintaining continuity of service to the International Space Station (ISS). China's human flights into space and its establishment of a space laboratory made spectacular headlines across the world. Its Lunar Exploration Programme also evoked great admiration as it progressively embarked on increasingly sophisticated missions to the moon.

In 2007 China carried out an ASAT test that destroyed one of its defunct weather satellites in polar Sun Synchronous Orbit (SSO). The test created a debris cloud that raised global concerns about the future sustainability of space operations. The US responded to the Chinese test with a test of its own.

The ASAT test went hand in hand with China's creation of a major military space capability. The Yaogan series of military satellites comprising

Electronic Intelligence (ELINT), Electro-Optical (EO) and Synthetic Aperture Radar (SAR) satellites became operational in 2010. Along with a dedicated series of military communications and Data Relay satellites this Yaogan constellation of about 40 operational satellites provides real time space surveillance capabilities over the Indo-Pacific Region. This space based C4ISR capability is a key component of China's Anti-Access Area Denial (A2AD) strategy directed against the US and its allies in the Indo-Pacific[4].

These developments brought the curtain down on the notion of a "peaceful space regime". Space had become an arena for a new arms race.

China's military space capabilities were also complemented by several initiatives to create a robust and competitive space ecosystem within the country. Today multiple entities within this ecosystem can provide the satellites and launchers required to meet China's needs in the space domain. A new series of launch vehicles, that are becoming operational, promise to further increase China's capabilities both in the civilian and military uses of space. Through commercial collaborations especially with Europe it has been able to overcome many technology gaps. It has successfully grappled with the US sanctions regime and has built, launched and delivered several large in-orbit satellites to many countries across the globe.

China has also broadened its user base in space through major investments in the pursuit of the sciences. The Chinese Academy of Sciences is now a significant player within the Chinese space ecosystem. Knowledge Power has become an important component of its Space Power Strategy. China launched the world's first Quantum Communications satellite in 2016. It was also the first country in the world to launch an Xray pulsar satellite for the accurate measurement of time. Collaborations with France and Europe have further enhanced its basic research capabilities[5].

The second decade of the 21st century also saw a major transition in the US approach to space. A very competitive and dynamic private sector emerged that offered new ways to space flight and exploration. Apart from traditional space giants like Boeing newer companies such as Elon Musk's Space X and Jeff Bezos's Blue Origin began to provide space services not only to meet the day to day needs for space services but also to help US requirements for human space flight and the exploration of the solar system. Space X launched the Falcon Heavy in 2018 that put a Tesla car into an inter-planetary Mars trajectory.

A Space Falcon rocket also carried the first NASA crew on a Dragon capsule resupply mission to the International Space Station in May 2020. This event marked the US return to human flight after the closure of the Space Shuttle Programme in 2011.

A technological revolution in "small satellites" triggered an avalanche of startups in the satellite, launcher and application domains. New companies like Planet Labs, Starlink and One Web started creating satellite constellations targeted at a broad spectrum of space markets across the globe. An increasingly vibrant space ecosystem has emerged that promotes the creation of new markets such as Space Tourism, the human exploration of the solar system, and space mining.

These have in turn triggered a Chinese response to develop a similar company based robust and resilient capability. Several startup companies are in the process of establishing constellations of small satellites for remote sensing and communications. China is also promoting several small satellite launcher programmes in industry that are derived from its ballistic missiles.

The technology competition between the two rivals is also backed by organizational changes

4. S. Chandrashekar and N.Ramani. China's Space Power & Military Strategy – The role of the Yaogan Satellites, ISSSP Report No. 02-2018. Bangalore: International Strategic and Security Studies Programme, National Institute of Advanced Studies, July 2018

5. S. Chandrashekar, "China's Space Programme – A Critical Evaluation", Internal NIAS Report, January 2019.

in both countries. China created a special entity called the Strategic Support Force (SSF) for space and military operations. The US in response has gone one step further and created a new service arm called the Space Force to deal with military space. The active promotion of vibrant domestic ecosystems appears to be a common feature though the methods adopted are quite different[6].

As the US China rivalry intensifies other countries are also taking a relook at their space systems. Europe collectively, France, Germany, Italy and the UK are making investments in enhancing space military capabilities. Japan too is moving towards a more aggressive space posture as it responds to the growing Chinese challenge in the East and South China seas. In the commercial domain too, all space powers are vying with each other to create robust space industries within the country.

As small satellite technology diffuses throughout the world reducing entry barriers to space operations more and more countries are getting into the space business. There is greater competition in all domains of space as the major space-faring countries endeavor to use all dimensions of space power to enhance their influence. Sustainability of the space domain for the benefit of all has also become an international issue.

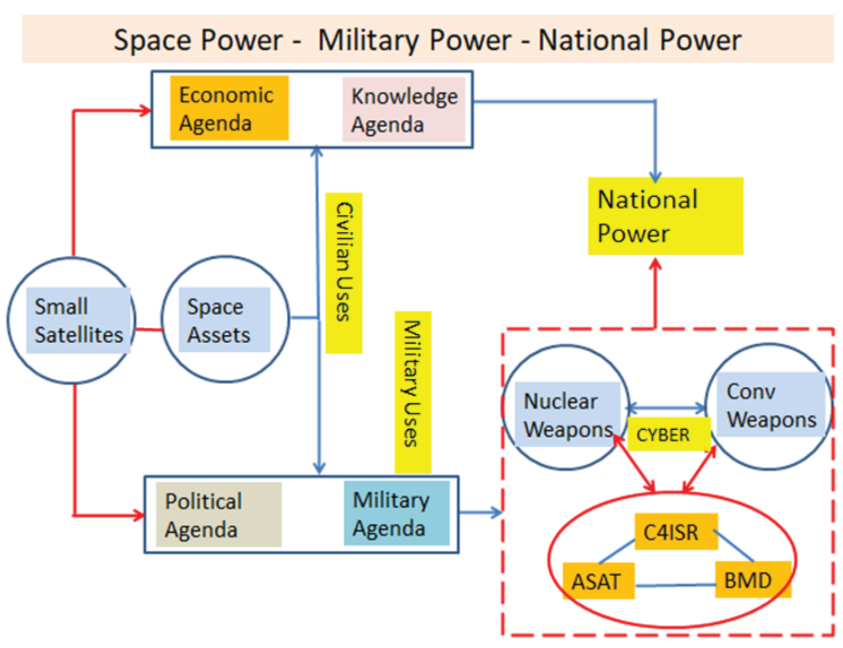
Fig. 1 provides an overview of these drivers and the connections between them.

As mentioned earlier, India too has embarked on several major initiatives to cope with these challenges especially from China. The following sections of this article take stock of Indian capabilities in the various functional areas of space and suggest a way forward. The later sections try and integrate the various strands into a coherent strategy for the country.

SPACE SITUATIONAL AWARENESS (SSA) – A MAJOR THRUST AREA FOR INDIA

Any aspiring space power must have real time information on the happenings in the space environment.

6. S. Chandrashekar. The China US Space Rivalry & the New World Order What Should India Do? ISSSP Report No. 03-2018. Bangalore: International Strategic and Security Studies Programme, National Institute of Advanced Studies, September 2018.



The current mix of Indian and foreign ground TT&C stations are adequate for tracking Indian satellites and space launches that emit radio signals. India has also made significant progress in setting up facilities for tracking inactive satellites and debris in Low Earth Orbit (LEO). These however need to be augmented and strengthened.

India therefore needs to make the investments needed to create a network of long-range radars and optical tracking stations for Space Situation Awareness. India is in the process of setting up this infrastructure and creating the necessary organizational arrangements for the routine monitoring of the space environment. These activities may need to be speeded up.

There is evidence that some of the advanced space powers have satellites in both LEO and GSO that can track other satellites. India needs to explore these possibilities as early as possible and establish operational capabilities.

There is a major need to grow the human resource base that can use public domain information to provide independent assessments of what is happening in space. A strengthening of such activities at Universities and think tanks would create a strong human resource base to support the growth of the more complex space effort that India must undertake.

Routine monitoring and a deeper understanding of what is happening in the space environment would be a very high priority area for an emerging space power like India. To establish space based SSA capabilities India may need a minimum of 10 small satellites along with associated launch services over the next ten years.

SATELLITE COMMUNICATIONS

Geostationary Communications Satellites

Till the end of September 2020, India has launched a total of 35 communications satellites into GSO. From an average of about one satellite per year the last five years has seen an increase to about two satellites per year. Most of these have been launched for meeting civilian needs. Only three of them the GSAT 7 launched by Ariane in 2013, the GSAT 6 and GSAT 7A launched by the GSLV Mark 2 in 2015 and 2018 may have been dedicated for military use. The services may also be using some of the capacities available on civilian satellites. Twenty of these 35 indigenous satellites have been launched using foreign rockets.

Though the INSAT / GSAT series of satellites have been providing communications for users in the country since the early 1990's transponder demand has always exceeded supply. The shortfall in demand has been met with the hiring of transponders leased from foreign satellites.

The market for Geostationary Communications Satellites comprises 4 sub-segments.

These are:

- Medium category satellites with masses less than 2500 kg;
- Intermediate satellites with masses from 2500 to 4200 kg;
- Heavy satellites with masses between 4200 and 5400 kg;
- Extra Heavy satellites with masses greater than 5400 kg.

The WGS series of US Defence satellites have a launch mass of about 6000 kg[7]. One of the largest capacity commercial communications satellite is Viasat. This has a launch mass of about 6700 kg[8]. The overall trends both in the civilian and military domain suggest a move away from the medium and intermediate category towards the heavy and extra heavy categories.

Indian Communications satellites that have been launched by foreign launchers like Ariane

7. Wideband Global Satcom (WGS) is a US led global advanced satellite system with several participating countries. A constellation of advanced communications satellites provides global connectivity for all military operations. Australia, Canada, Denmark, Luxembourg, Netherlands and New Zealand are part of this global system. See http://www.afspc.af.mil/library/factsheets/factsheet.asp?id=5582
8. http://www.nasaspaceflight.com/2011/10/ils-proton-m-launch-highest-throughput-satellite-viasat-1/

fall in the intermediate to heavy categories. Indian Communications satellites that have been launched by the indigenous GSLV launcher fall in the medium to intermediate satellite categories[9].

This relative positioning of Indian satellites vis a vis world trends suggests that Indian capabilities for Communications satellite manufacture needs to move from the intermediate class towards the heavy and extra heavy categories. **Fig. 2** benchmarks Indian communications satellites against global trends.

Another major trend that could directly improve Indian communications satellites is a shift towards the use of ion propulsion for moving satellites from Geostationary Transfer Orbit (GTO) to the GSO. Over half the mass of a typical Geostationary Communications satellite is made up of propellant. Most of this propellant is consumed in moving the satellite from GTO to GSO. Though ion propulsion also requires some mass it is significantly less than the heavy chemical propulsion systems that spacecraft carry.

In March 2015, the first two all ion propulsion satellites built by Boeing were launched aboard a Falcon X launcher[10]. The Asia Broadcast Satellite 3A (ABS 3A) weighed 1954 kg with 48 transponders and the Eutelsat 115 W B satellite with a mass of 2205 kg carried 48 transponders. Since then most satellites have used ion propulsion to reduce mass, improve performance, increase life and reduce costs. Though India has developed and experimented with ion propulsion they have not been inducted into operational satellites. This transition would enable Indian satellites to improve their performance to match those currently provided by Heavy and Extra Heavy satellites.

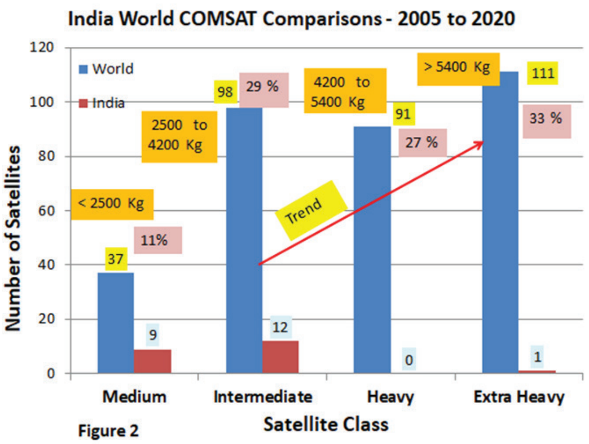


Figure 2

Current domestic demand for transponders is estimated to be around 500 with a shortfall in domestic supply of about 50%. Very conservatively one can expect this demand to double to about 1000 transponders by 2030. Along with this expansion in the civilian domain a major military requirement has begun to emerge. Space and air-based Reconnaissance platforms need bandwidth to transfer data over wide geographic areas. These require significant space-based communications capacities. A conservative assessment of these requirements indicates a need for at least 500 transponders for the defense and security agencies. Assuming some spares a total capacity of about 1600 transponders of different kinds may be needed by 2030. About 40 satellites in GSO may be needed to provide this capacity.

The GSLV Mark 111 can launch intermediate class satellites. Along with ion propulsion, throughputs and capacities of the intermediate class satellites can be enhanced. Commercial competitiveness may however need India to build and launch heavier satellites too. In the short term such requirements may need the use of a foreign launch vehicle. To rectify this shortfall in launch capacity a bigger launcher may need to be developed in the medium to long term. The future needs of inter-planetary exploration and the human space flight programme may also warrant the development of a bigger launcher.

Data Relay Satellites in GSO

Ground stations are normally used to receive

9. For an overview of these trends in satellite masses see Federal Aviation Administration, "The Annual Compendium of Commercial Space Transportation: 2014", February 2015, PP 100-104 available at https://www.faa.gov/about/office_org/headquarters_offices/ast/media/FAA_Annual_Compendium_2014.pdf

10. Stephen Clark, "Boeing's first two all-electric satellites ready for launch", Spaceflight Now March 1, 2015.

the data transmitted by remote sensing and reconnaissance satellites. Some satellites store the data onboard and then transmit it to a ground station when they are visible over them.

Three or more Data Relay Satellites in Geostationary Orbit located suitably over a country provide a way to obtain real time coverage over a large part of the earth. The US currently has nine such satellites in orbit that cover the Atlantic, Pacific and Indian Oceans. China has four Data Relay Satellites as of end 2018.

As the need for real time ISR increases India might also have to consider having these satellites as a part of its military constellation. These are very similar in architecture to heavy or very heavy GSO communications satellites. About five such satellites may be required over the next ten years.

Small Satellite Constellations in LEO for enhanced connectivity

Small satellites have emerged as a major thrust area that promises to transform the global space industry cutting across all traditional space applications. These constellations could be dedicated to military use or could be a part of a commercial network. The US start up ecosystem, Europe and China too are going ahead establishing such constellations for commercial as well as military needs.

Several start-up companies such as One Web are partnering with satellite manufacturers such as Airbus to establish large constellations of small satellites for providing global broad band Internet connectivity.

The constellation proposed by One Web will have 650 satellites orbiting in 20 different planes at altitudes of 800 and 950 km. The satellites which are expected to weigh about 175 to 200 kg will be launched 32 to 36 at a time on board an Ariane Soyuz launcher[11].

India has so far had no experience with orbiting constellations of communications satellites. Current rules and regulations also seem to inhibit private sector investment in these emerging opportunities. The burgeoning communications market in the country is ready for new initiatives. There is a market for at least two or three players to provide various communications and data services via a LEO constellation. The military too could use such a constellation for its operational needs. There is a large global demand for small satellites and any surplus capacity could be used to promote exports. Keeping these factors in mind one would expect that the potential market for small communications satellites in India would be at least 50 satellites per year over the next ten years. The satellites whose masses can be in the range of 150 to 200 kg can be launched three or four at a time by the PSLV launcher.

REMOTE SENSING

Civilian Uses

The launch of IRS 1A in 1988 marked Indian entry into the operational phase of the civilian remote sensing programme. Since then 30 satellites have been launched catering largely to civilian needs with some military applications. The pace of launchings has also picked up over the last decade from about one satellite per year to two satellites per year.

The current Indian remote sensing constellation consists of both Electro-Optical (EO) as well as Synthetic Aperture Radar (SAR) satellites. **Fig. 3** provides an overview of the trends in Indian Remote sensing capabilities.

After achieving a world class capability in both PAN and multispectral capability through the launch of IRS 1D in 1997 India has chosen to separate out the hi-spatial resolution Panchromatic (PAN) function from the multispectral (MSS) function and provide them through different satellite platforms. However, starting with Cartosat 2D the hi-resolution PAN data has been re-integrated with the MSS on the same platform.

The recently launched Cartosat 3 satellite provides a PAN resolution of about 0.25 m with a MSS resolution of about 1m. This is on par with

11. http://spaceflightnow.com/2015/07/01/oneweb-launch-deal-called-largest-commercial-rocket-buy-in-history/

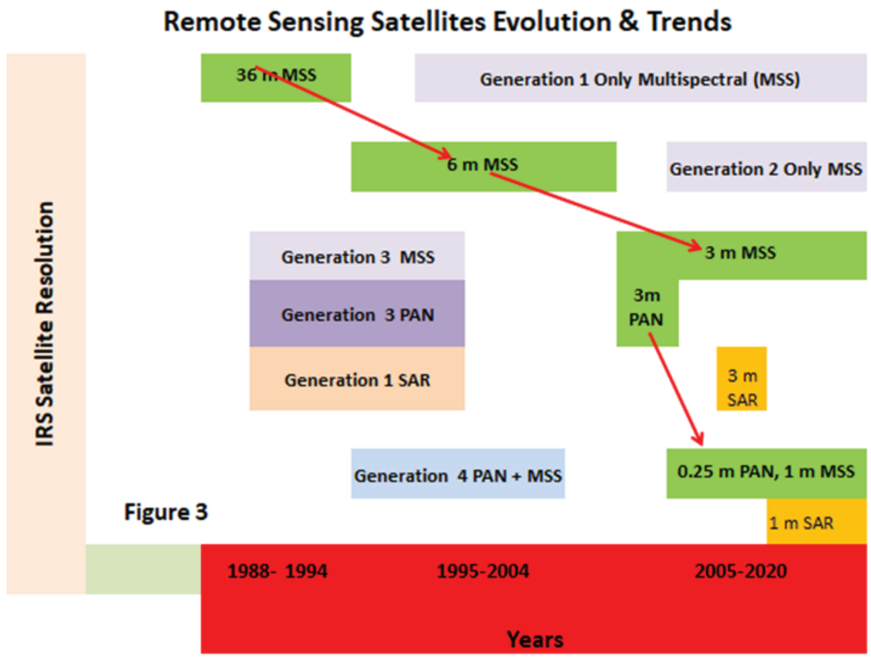


Figure 3

the current global standard for both PAN and multispectral data.

The first indigenously built RISAT 1 SAR satellite was launched in 2012[12]. This satellite had a spatial resolution of about 3 m in the spotlight mode. In 2019 two improved RISAT 2B and RISAT 2BRI derived from the earlier Israeli supported RISAT 2 satellite were launched. These carried X band SAR payloads and were successfully placed in a 37-degree inclination orbit. These satellites are reported to have at least a 1 m resolution capability that is comparable to what other international satellites offer.

Though functionally Indian satellite capabilities are comparable to state of art they appear to be heavier than current world standards. Continuity of service to the current user community may need the launch of at least two larger satellites a year for the next ten years.

An emerging trend that could play a big role in the future applications of remote sensing is the growing importance of high-quality imagery available from small satellite constellations launched by private companies across the world. Planet Laboratories a San Francisco based start-up company provides 3 m resolution colour imagery. It plans to provide a complete picture of the earth every day using images produced by more than 100 small satellites. These satellites weigh around 5 kg and are launched as constellations into earth orbits of various inclinations. Several other companies across the world are following this approach. Many advanced countries are also making available real time satellite imagery for use by commercial companies and service providers.

India has so far not actively promoted small remote sensing for specific application areas that include the military domain. Just as in the case of small satellites for communications such constellations are best provided by private companies. The applications and service potential are a huge business opportunity. The civilian market can easily accommodate two or more players providing data. The application potential of real time data is also huge providing even more opportunities to foster economic growth and development. This requires a national capacity of about 50 small satellites per year for civilian as well as military applications.

12. http://www.isro.gov.in/sites/default/files/pdf/pslv-brochures/PSLVC19.pdf

Intelligence, Surveillance & Reconnaissance (ISR) Needs

Though Indian capabilities in remote sensing are on par with world standards India lags in providing national ISR data to the military and intelligence agencies. China's creation of an ISR constellation of over 40 operational satellites provides a real-world example of what is needed. This constellation comprises two types of Electronic Intelligence (ELINT) satellites, Electro-Optical (EO) satellites as well as Synthetic Aperture Radar (SAR) satellites in various orbits. This ISR capability is integrated with its military communications satellites as well as its SSA capabilities to provide real time information[13]. India has so far not launched any ELINT satellites. Its capacities for building and launching EO and SAR satellites are also limited. A capacity to manufacture about 20 ELINT, EO and SAR satellites per year for a dedicated military ISR capability is needed to bridge this gap. This expansion could also be used to promote civilian needs. Given current tends many of them would qualify as small satellites. The PSLV launcher could be used to launch them three or four at a time.

SATELLITE WEATHER SERVICES

Monitoring the weather using satellites has become an operational service around the world. Advanced space powers use a combination of geostationary and polar orbiting satellites to provide weather forecasts. The sensors that are carried on both these platforms and the platforms themselves have seen several generations of evolution. Imaging sensors, sounders that measure vertical profiles operating in the visible, infra-red and microwave regions of the spectrum along with specialized instruments for measuring substances like ozone and other pollutants provide a wealth of data. These are used for making short, medium and long-range forecasts as well as for monitoring the earth environment. All these satellites also come equipped with the capability to receive data from data collection platforms on the ground[14]. In most countries civilian and military weather services have been merged into one service that cuts across departmental boundaries.

India currently uses only weather satellites in GSO for forecasting purposes. Historically the meteorology payload for weather was carried on the INSAT series of Geostationary communications satellites. Starting in 2013 the weather function has been decoupled from the communications function. The INSAT 3D and INSAT 3DR dedicated weather satellite currently provide operational services. Other orbiting satellites such as OCEANSAT and SCATSAT provide data over the ocean areas for improved weather forecasts. With a mass of 2200 kg INSAT 3DR is on par with European second-generation weather satellites.

One GSO weather satellite may be needed every three years to maintain the current constellation. These could be launched on the GSLV. In addition, a constellation of three orbiting satellites operating in an 800 km sun synchronous orbit may be needed to improve weather forecasting capabilities especially for military operations. These could be launched by the PSLV. Taken together both these needs will need a capacity of about 10 weather satellites over 10 years.

NAVIGATION SATELLITES

India has so far launched 9 navigation satellites into GSO and inclined GSO orbits as a part of an Indian Regional Navigation Satellite System (IRNSS). The system is designed to have 3 satellites in GSO and four satellites in 30-degree inclination geosynchronous orbits (IGSO). The constellation will provide navigation information to users within the Indian Ocean region.

13. S. Chandrashekar and N. Ramani. China's Space Power & Military Strategy – The role of the Yaogan Satellites, ISSSP Report No. 02-2018. Bangalore: International Strategic and Security Studies Programme, National Institute of Advanced Studies, July 2018.

14. Gary Davis, "History of the NOAA Satellite Program", http://www.osd.noaa.gov/download/JRS012504-GD.pdf

Globally navigation satellites are considered strategically important. Dependence on an outside supplier of these services makes countries vulnerable. The US was the pioneer establishing the GPS constellation of 24 operational satellites in differently inclined 20000 km Medium Earth Orbits (MEO). The GPS is now into its third generation of satellites. Over time the lines between civilian use and military use have blurred. The GPS usage in the civilian domain is everywhere and it has become the global navigation and time measurement standard. Russia too has a similar GLONASS system. Europe as a part of its security strategy is also investing in its own Galileo system that is almost operational. China initially used a system of GSO and inclined geosynchronous satellites like the IRNSS. It has now transitioned into its next generation Beidou global navigation satellite system with a launch of several Beidou satellites into GSO, IGSO and MEO. This constellation of 35 satellites is operational and provides navigation services across the world.

As Indian strategic and commercial interests become increasingly global India may also have to move away from a regional to a global focus. The country may need a navigation constellation like those of the other countries. About 40 navigation satellites may be needed over the next ten years to meet Indian needs. These satellites may need to be heavy requiring launch by the GSLV.

Indigenously developed atomic clocks for use in navigation satellites will also be a high priority technology for India.

INDIAN SCIENCE & KNOWLEDGE SPACE MISSIONS

The launch and the success of the first interplanetary Indian mission to the moon Chandrayaan 1 in 2008 evoked an overwhelming response from the public. Interest in space and the pursuit of knowledge especially in the younger generations of Indians peaked. Further Indian missions dedicated to exploration of the solar system such as Mangalyan to Mars, Astrosat and Chandrayan 2 to the moon have sustained the continuing Indian interest in fundamental research related to the origins of the universe and a deeper understanding of the solar system. Further missions to Venus, the Sun as well as Mars are underway.

Globally major space powers such as the US, China, Europe collectively as well as countries such as France and Germany are all making investments in space missions related to fundamental research. China's launch of a Quantum Communications satellite, its missions to the moon and the launch of an Xray Pulsar satellite have already been touched upon earlier. This competition is likely to intensify in the coming decades.

An aspiring power such as India needs to recognize this reality. Investments in the pursuit of basic knowledge via space missions are an important component of a country's political and knowledge power.

About 10 satellites dedicated to basic science missions may be needed over the next ten years. All these satellites are likely to be quite complex using state-of-art technology. The missions may also involve large satellite masses requiring the use of the GSLV. For future missions beyond the five to ten-year horizon a bigger launch vehicle may also be needed.

THE HUMAN SPACE FLIGHT PROGRAMME

The Indian Human Spaceflight Programme, Gaganyaan, was formally approved in 2018. The plan involves two unmanned flights of the orbiter followed by the launch of three astronauts some time in 2021. Given the current COVID crisis these milestones are likely to be delayed.

Globally too there is increasing competition to promote human space flight both for commercial purposes like tourism as well as for political prestige. About ten human mission capsules along with ten GSLV launchers may be needed in the next ten years for meeting the needs of the human space flight programme. To sustain safe human presence in the space environment will call for substantial investments. A bigger launch vehicle that would improve Indian abilities to mount more ambitious missions may also be needed.

SPACE DEFENCE

India conducted its first successful ASAT test in 2019. Given current trends in the military uses of space India needs to protect its assets in space. About ten satellites with associated launchers may be needed for meeting these development needs over the next ten years.

India may also need to keep BMD options open. Early Warning Satellites in GSO are needed for this purpose. About 5 large satellites in GSO over the next ten years may be needed.

LAUNCH VEHICLES & LAUNCH INFRASTRUCTURE

The launchers needed for launching various types of satellites have already been covered. The PSLV and GSLV vehicles will remain the workhorse vehicles for the next ten years.

Indian ambitions to be globally competitive in space in areas like human space flight, larger communications satellites as well as inter-planetary exploration will need the development of a new launch vehicle.

The market for small satellites is also exploding. India may need multiple launchers for meeting the needs of this vitally important segment of the market.

Given the large increase in the number of satellite launchings new launch sites as well as mobile launching platforms may be necessary.

OVERALL ASSESSMENT

Table 1 provides a summary of the various satellites and their associated launchers needed to meet India's space requirements.

A total of 1360 satellites of all types and categories are needed. Over a 1000 of these would be small satellites in the weight category of 100 to 200 kg. Many of them would be launched three or four at a time by the PSLV while some may require dedicated smaller launchers.

Over a 100 of these satellites would be satellites in the 2000 kg to 4000 kg class. These would require dedicated launches using the GSLV.

280 satellites would fall in the 500 kg to 1000 kg class that could be launched by the PSLV.

Table 1 also provides a first level estimate of the launch capacities needed to meet these needs. Over a 100 GSLV launches, about 280 PSLV launches and over 200 launches of smaller launchers are required. This translates into 40 large launchings every year along with about 20 launches of smaller vehicles.

IMPLICATIONS FOR AN INDIAN STRATEGY

A major increase in launcher and satellite capacity is needed to operationalize current capabilities. The launch and satellite infrastructure also need to be expanded. The human space flight programme and the interplanetary missions require a major effort and significant resources. While some prioritization and phasing out is possible, an emerging space power like India cannot afford to ignore any of the dimensions.

In view of the large requirements of space systems for civilian and military applications it is necessary to promote multiple manufacturers of satellites and rockets for these operational space missions. Remote sensing, ISR, Communications, C4, navigation and weather satellites with their associated launchers can be built in industry. Even launch and satellite mission operations can be handed over to industry. Wherever new products and services are to be provided, the development can be carried out within respective government organizations and then transferred to industry for manufacture in larger numbers. Large Communication satellites, ELINT, EO, SAR and some navigation satellites may fall in this category. As the industry evolves many of these developments can also be carried out in industry through a suitable tendering process. A well-designed regulatory and policy framework coupled with buy back guarantees will motivate Indian industry to make the investments needed

Table 1 : Satellite & Launcher Requirements 2020 - 2030

Function	Satellite Mass (kg)	Orbit (km)	Nos over 10 years	Launchers			Comment
				PSLV	GSLV	Small	
SSA function in LEO & GSO	500 - 1000	LEO & GSO	10	8			Emerging trend
Communications Function							
Civilian Advanced Satellites	2000 -4000	GSO	25		20		Ion Propulsion Procured launches
C4 System Military (DRS)	2000 -4000	GSO	15		15		Ion Propulsion GSLV launch
Data Relay Satellites	2000 -4000	GSO	5		5		Ion Propulsion GSLV launch
Civilian small satellite constellation	150 – 200	LEO	400	90		40	Ion Propulsion Mix of Small & PSLV
Military small satellites C4	150 – 200	LEO	100	20		20	Ion Propulsion Mix of Small & PSLV
Remote Sensing & ISR Functions							
Continuity civilian services	500 -1000	SSO LEO	20	15		5	Ion Propulsion Mix of Small & PSLV
Dedicated ISR military services	500 – 1000	SSO LEO	200	40		40	ELINT, SAR, EO capacity needed
Dual use constellations	150 – 200	LEO	500	100		100	Ion Propulsion Mix of Small & PSLV
Weather Services							
GSO Weather Services Continuity	2000	GSO	3		3		Ion Propulsion – GSLV launch
SSO LEO Weather Services	500 – 1000	SSO	7	7			PSLV Launch
Navigation Services							
GSO, IGSO & MEO constellation	1500 – 2000	GSO, MEO	40		40		Ion Propulsion – GSLV launch
Science Knowledge Missions							
Exploration & Science Projects	2000 - 4000	Deep Space	10		10		Ion Propulsion – GSLV launch
Space Defence							
ASAT related	100 -200	LEO, GSO	10			10	Rendezvous, evasion, docking
Early Warning BMD	2000 – 4000	GSO	5		5		Ion Propulsion – GSLV launch
Human Space Flight	3000 – 4000	LEO	10		10		Human life capsules major effort
Total			1360	280	113	215	

Notes: C4 – Command Control Communications & Computers, **ISR** – Intelligence Surveillance & Reconnaissance, **DRS** Data Relay Satellite **ELINT** – Electronic Intelligence, **EO** – Electro-optical, **SAR** – Synthetic Aperture Radar, **GSO** – Geostationary Orbit, **SSO** – Sun Synchronous Orbit **MEO** – Medium Earth Orbit, **LEO** – Low Earth Orbit, **PSLV** – Polar Satellite Launch Vehicle, **GSLV** - Geostationary Satellite Launch Vehicle for meeting routine civilian and military needs. This will also ease the burden of government spending on the space programme and create a vibrant space ecosystem in the country.

The Human Space Flight Programme as well as the science missions such as the exploration of the solar system involves complex engineering and technology management skills. These may continue to be managed by government entities responsible such as ISRO with the maximum possible involvement of Indian industry.

One area where major changes are needed relates to the military uses of space. Apart from the gaps in technological capabilities, one of the biggest challenges confronting an emerging space power like India is the integration of the various space-based military components into a cohesive working architecture. There are a multitude of organizations that deal with different parts of it. Their activities need to be aligned for meeting the strategic challenges posed by role of space-based information in fighting and winning modern wars. **Fig. 4** provides an overview of the various space military components that need to be brought together for this purpose.

The parts of Figure 4 marked in red are of particular concern. SSA, C4ISR, Weather, Navigation, ASAT and BMD components need to be linked seamlessly with tactics and strategy cutting across different geographies. This represents a significant organizational and institutional challenge.

As mentioned earlier a key area that affects all uses of space is a state-of-art SSA capability. A new launcher that can place heavier payloads in orbit for meeting the future needs of communications, human space flight and inter-planetary exploration is also needed.

Different routes to the development of smaller launchers could also be pursued. This could involve modifications to missiles, new launcher development as well as industry led developments of smaller launch vehicles. The regulatory and policy regimes required for this purpose need to be put in place quickly. A major government led small satellite initiative could also provide a fillip to the nascent space ecosystem in the country.

There are also several areas and specific technologies that need to be supported. Annexure 1 provides a listing of some of these critical areas.

CONCLUSIONS

Space Power is an increasingly important component of national power architectures. India needs to recognize this reality as it seeks to take its rightful place in the comity of nations. **Fig. 5** provides the relative competitive positions of the major space powers on the global Space Industry evolutionary S curve.

The US China rivalry will drive global developments in space too. Whilst the new global power order is likely to bring anti-China countries closer, there is also a trend towards more inward-looking policies amongst space powers. If Indian aspirations towards a greater role in world affairs

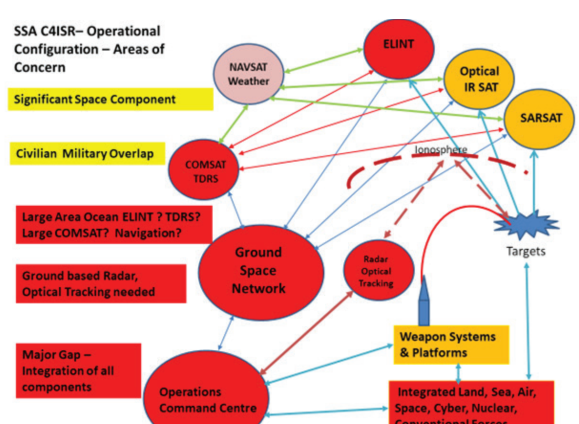


Figure 4

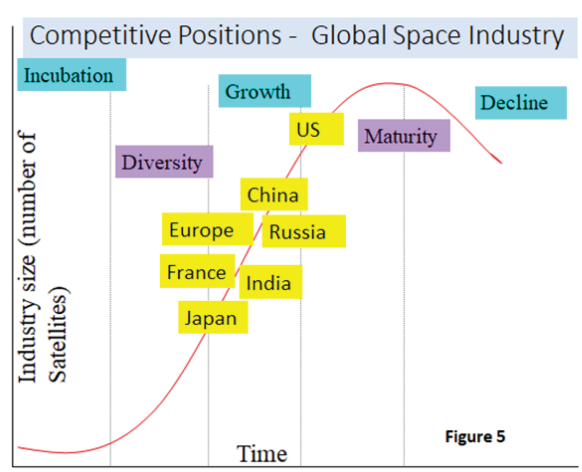


Figure 5

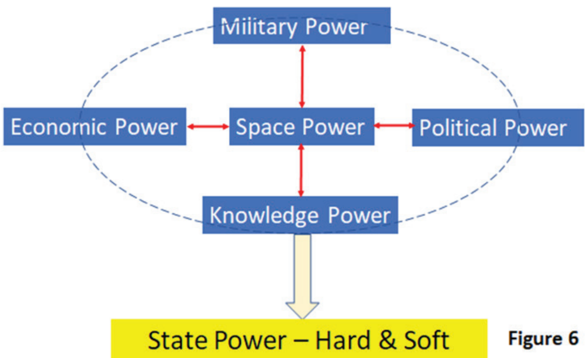


Figure 6

Space & Comprehensive National Power

is to be realized it needs to make sure that it is strong in all dimensions of national power. Space is an important part of national power architecture. Figure 6 provides a framework that links space to national power aspirations.

As we can see from **Fig. 6** space has become an increasingly important part of growth and development. The major space powers are competing across all dimensions. The competition between the US and China is increasingly driving the global space industry. In this realm of competition and Realpolitik India cannot be left behind. A major national initiative along the above lines can accelerate India's development and transform it into a major power on the world stage.

ACKNOWLEDGEMENT

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Annexure 1 Critical Infrastructure & Technology Concerns

Critical Infrastructure & Areas of Concern	Comment
Space Situation Awareness	
Radar Network for Tracking Space Objects & Debris	Gap area for Immediate Action
Optical & Laser Ranging Facilities for Tracking Space Objects	Gap area for Immediate Action
Capabilities & Capacities for Monitoring the Space Environment	Gap area for Immediate Action
Ship borne TTC stations for space missions	TDRSS is an alternative for future
Orbit based Scientific Studies (International Collaboration)	Geodesy, Astronomy, Global Tracking
C4 & Related Areas	
Ion Propulsion for satellite applications	Critical to redress major launcher satellite gaps
Satellite to Satellite Radio Links	Need for switching via satellite
Satellite to satellite Laser Links	Need for optical switching
Secure Communications	Encryption, Frequency hopping, Anti jamming
C4 Network Operations	Connectivity within C4 commands + Civilian
LEO C4 Internet Constellations	Architecture, Design, Validation key areas
Antennae Beam forming Beam Shaping	Gap area for Advanced C4 TDRSS Satellites
ISR Related Areas	
ELINT Technology Development	Gap Area for Immediate Action
Infrared Technologies and Imaging Sensors	Needed for military & BMD applications Gaps
Improved Integrated Optics for Imaging sensors	Capabilities may need enhancement
SAR weight reduction initiatives	Benchmarks show Scope for improvement
ISR Small satellite development	Need for Catch up
TDRSS related Compatibility capabilities	Interface issues – compatibility issues
Data Processing especially SAR data Processing	Need for speedier processing of Satellite Data
Use of commercial or open source data for strategic applications	Improve National capabilities to use Data
Space Based Support Services	
TDRSS related	Technology development compatibility issues
Infrared Microwave imagers and sounders for weather	Need to improve complement of sensors
High precision clocks for time measurement navigation	Alternatives for time measurements
Small Satellites	
A National Initiative on Small Satellites – Multiple Centers	Emerging area for military and civil use
Launchers	
Scale up Improvements PSLV	Need to produce in numbers. Industry role
Operationalization GSLV - Scale up for Production	Launcher production and launch by industry
Agni 5 modifications for Space Launch	Useful Complement – small satellite initiative
New Small Launcher Development	Multiple launcher development
Space Weapons	
Retain Develop Technology Options for BMD, ASAT	Link to good SSA – Midcourse BMD extension
Technology Development Early Warning Satellite	Option for a Possible Future
Monitor Space Geo-Political Environment – other Space Players	Link to good SSA – technology assessments
Integrated SSA & C4ISR Capabilities	
Need to restructure and re-organize operational capabilities	Integrated Mission mode network operations
Strengthening the Planning & War Strategy capabilities	Link to threat scenarios wars and conflicts
Strategy & Doctrine Related	
Re-organization & Restructuring of the National Security System	Major challenge to recognize new realities
Link Challenges, Capabilities Capacities to Strategy & Doctrine	Information Centric NSC - aspiration

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Emerging Technologies and Business Growth: The Engineering Imperatives

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INTRODUCTION

The world has been on a cusp of a technological revolution. In today's fast paced hyper-competitive global economy organisations have to be prepared from within to cope with the change. Technology integration must be in harmony with corporate capabilities and local culture. Advances in materials science, information technology, electronics, computer science etc. have enabled the technological base of many industries to change rapidly and unpredictably causing a paradigm shift in technology application.

The beginning of 21st century had undoubtedly brought radical change in our lives, and we have been experiencing one of the most thoroughly documented industrial revolution in mankind's history. To navigate this turbulent geo-political and economic time, businesses need leaders with foresight, resilience and agility. Technology is transforming the global economy. It's changing the very fabric of business and organisations. There are other forces at play too; globalisation and protectionism, changing expectations of individuals in the workplace, shifting social mores and values, new types and levels of connectivity and demographics.

The global economic and business landscape has been changing at a speed and with an intensity that seems unprecedented. Factors reshaping the world include climate change, resource scarcity, geopolitical conflict tempering growth, unpredictable emerging markets, widening inequalities, ageing population with a burgeoning middle class, huge shifts in corporate and political power, and the increasing pace of digital innovation; to name, but a few.

The current business environment makes all this particularly challenging. Political instability, volatility in currency and commodity markets, growth of emerging markets, constraints on credit availability, rapid changes in technology, and a broadening of business risk exposure are among factors creating a complex and uncertain climate. Also relevant has been the 2007-8 global financial crisis, and heightened stakeholder focus on sustainable wealth creation, with a more equitable balance between the pursuit of growth and profit, its long-term sustainability, and appropriate organisational controls. Strong financial management is vital, but increasingly difficult to ensure.

The year 2020 started with Covid-19 global pandemic, an unprecedented, unrelenting human tragedy; one of the worst health and finance emergency the world has ever witnessed. It put brakes on economic growth, pushing the world into largest recession since 1933. The suddenness, the spread, and severity of the pandemic caught governments, business and society around the globe unaware. It has dramatically disrupted life and business significantly, impacting economy, health and safety. Geo-political and economic disruptions have disrupted strategic global supply and value chains. Health, lives, inclusion, diversity and sustainability have been at risk during this crisis.

Agile board leaderships with conceptual skills were required to steer the organisational and technical transformations, through this turbulent period. Organizations needed a digital recovery with accelerated re-skilling of staff, safe contactless engagement with dynamic customer insights and digital outreach. As we emerge from the rigours of the lockdown, data analytics has helped accelerate the recalibrated corporate journey, through cloud based data platforms to reboot the operational economy. The pandemic forced their desire and opportunities for long term sustainability, with only short term sacrifices and putting outcomes based governance into action. The Covid-19 Pandemic is not going to go away soon. Old days and old norms won't return fully. New options will reshape our portfolios, with revised market offerings. Although remote working has not been a panacea, we are likely to retain some of its positives, like 'online training' and 'virtual meetings' etc.

REVIEW OF EMERGING TECHNOLOGIES

Review

Technology has been moving at an exponential pace. More has changed in last 50 years, than in the previous 500 years. The emerging technologies and disruptive innovations are altering the business landscape, and driving the next phase of business growth. Technologies, such as mobile communications, cloud computing, digitization, robotic process automation, Artificial Intelligence (AI), Data Analytics, Internet of Things (IoT), and blockchain, are changing the way work is done and the workplace organized. Never before, so many technological trends have matured and converged at the same time, changing the playing field itself. These are poised to deliver enormous productivity gains. The world of tomorrow will be shaped by three of the biggest mega trends of urbanization, industrialization, and digitization.

Technology will play a significant role in shaping the global economies in the coming decades. Digital governance is good governance; digital delivery is faster delivery; and digital monitoring is effective monitoring. 'Internet of Things' is the latest trend of connecting sensors from everything, from door locks and wearable devices to traffic signals and a vast network of devices, to a centralized automatic control. Decentralised World Wide Web, where instead of silos, systems run by Facebook, Google and twitter with a shared infrastructure, are operating much more collaboratively. IT infrastructure and most of all their data and Cloud solutions fused with disruptive technologies – like Blockchain, IoT, big data, and predictive analytics can revolutionize businesses and industries. To win in the cognitive era, data matters.

Today, emerging technologies, disruptive business models and rising customer expectations are reshaping the way business is done. The digital onset has changed our everyday lives. Disruptive innovation is altering business landscape, across the world. Constant disruption through the innovative use of emerging and existing technologies is in-fact the new normal today. Organisations have to constantly re-invent themselves and their business processes and offerings, to stay relevant.

Technologies such as Artificial Intelligence (AI), Robotic Process Automation (RPA), Distributed Ledgers or Blockchain, Internet of things (IoT), Data Analytics, and Edge Computing are poised to deliver enormous productivity gains to companies in the times to come. These emerging technologies will shape our future more powerfully, than any other innovation in the last century. Rapid advances in data storage and computer processing power have dramatically changed the game in recent years. These emerging technologies are also enabling executives to envision new business models, and create differentiated products and services for customers.

So far, the power of all advanced technologies has been restricted to select institutional investors, and algorithm-based trading. The retail market has mostly been distant from these technologies. Smartphone and likes have been the biggest enablers for current financial inclusion. New technologies like Artificial Intelligence and advanced Analytics will make managing and investing money easier than ever before. Scaling up the revolution is driving India's transition towards a digital economy. The quest for hearts, minds, and wallets of the consumer is getting harder. Brands are vulnerable to sweating consumer mood. Social media's viral and trigger-happy nature has put tremendous pressure on consumer trusts in brands.

We foresee a confluence of IoT, IA, Blockchain and decentralized 'World Wide Web'. By the next 5 years, the integrity, privacy and security of data will remain our prime concerns. Economic and societal benefits of this new era will not be realized, if the human side of the equation is not supported. The advent of machinery and gadgets that serve to aid humans in making tasks easier, are seeking to expose our weaknesses as a species and making ourselves redundant. Our physical and digital realities are colliding and fusing to create new experiences and transform industries and processes.

There have been tectonic changes in the world which are not linear, but exponential in nature. For every transformation, destruction is a must. Shiva destroys to recreate. Transformation caters for changing organizational culture, and people's mind set. Technology changes quickly, but organisations adjust slowly.

Disruptive innovation is altering business landscape across the world. Constant disruption through the innovative use of emerging and existing technologies is in-fact the new normal today. Organisations have to constantly re-invent themselves and their business processes, to stay relevant. Legal and compliance environment too is changing, as regulators have to evolve new sets of compliance frameworks that can effectively deal with and monitor the new ways of doing business to stay ahead of the curve.

It is the dawn of a new era for those who work for a living, and even those who live to work. The future of work looks scary. Digital technologies are changing life and business in radical ways. Cloud computing, mobile communication, digitisation, automation, robotics and artificial intelligence etc are changing not only the way work is done, but also the way workplace is organised. The world by 2050 will be a place in which robotics, advanced materials and emerging technologies could make our lives longer and unrecognisable.

Whatever the size of the business, technological change is having an impact. The revolution has started and adaptation is critical. Human societies are living and benefitting from a life based on electronic footprints. The combination of the burgeoning 'Internet of Things' (IoT), the shift from 4G to 5G and the rise of new emerging communication tools and technologies is changing the connectivity paradigm and driving instantaneous communication possibilities for global reach.

In this age of creativity, innovation and digital revolution, it is important to keep pace with the change. Business leaders are trying their best to find ways to remain relevant in the market and get ahead of others. Disruptive innovation has become the game changer in today's scenario. Organisations in today's digitally-driven era have to deal with huge volumes of real-time data, and create personalised consumer experiences to survive. New technologies such as cognitive computing, artificial intelligence (AI), and robotics are a boon. Artificial Intelligence (AI) and Robotics are slowly entering all spheres of our life. They are expected to be the biggest drivers of economic growth, and with impact the job scenario in the coming years.

Data Management

New age technologies can progress seemingly unrelated data, to help generate valuable insights. There are various sources of data: social media channels, publicly available information, and data generated by organisations. All these data types are being integrated, processed, catalogued, glossarised and validated as 'Harvested Data'. Most organisations still struggle to use data effectively.

The internet is just an open source of untreated, unfiltered information. Most businesses don't care about what you know; they only care about what you can do, with what you know. We need to Select a 'crowd' service provider, with fool-proof security, and a strong business presence. 'World Wide Web' founder Tim Berners Lee, said "I want the web to reflect our hopes and fulfil our dreams, rather than magnify our fears and deepen our divisions." It is up to the decision makers to press, reset, and change the way global internet giants operate in India.

'Data readiness' is critical to business, and is ensured by:

- Profiling and remediating data quality issues, relating to master data and reference data.
- Identifying master data management issues impacting the digital initiatives, and defining an approach to resolve them.
- Recommending data governance strategy, for proactive data management and quality assurance.
- Formulating the data acquisition and storage strategy, for the newly acquired data sources, especially for unstructured data.
- Chalking out a plan to ramp up skill, technology, and governance model to support the data execution.

The integrity, privacy, and security of data remain our prime concern. Corporates create and own domain-specific data sets that build vertical industry solutions in specific professional fields like healthcare etc. Technology is a business enabler. Enterprises need cognitive solutions that turn vast amount of data into insights for competitive advantage. As data privacy and technologies become pervasive, disruptive, and liberating, we need to think about responsible 'Data Analytics'.

Enterprises need cognitive solutions that turn vast amounts of data into insights and competitive advantage. They need access to a cloud platform not only for IT capability, but for speed and agility. Cloud solutions fused with disruptive technologies can revolutionize businesses and industries. By 2021, 98%of organisations expect to be embracing multi-cloud architectures. A hybrid multi-cloud storage approach can optimize the movement, placement and management of your data.

Trends predict new age marketing would be powered by data. Driving digital marketing would include personalized, real time, content and influence marketing. Personalized content marketing has emerged as the top trend, driving digital marketing across India, a using behavioural data to understand buying habits, patterns, and changing needs. Thought leadership will become a valuable driver of trust, among buyers.

India ranks number one in using data, more than China and USA put together. EU, Japan and China have taken decisive steps in creating data rules. India needs rules, dealing with all aspects of the digital business. This will set the foundation for a thriving digital business space, no-longer monopolized by a few. Regulation tightening, data privacy, and security have become top concerns of our government. The Indian government set up the 'Srikrishna Committee' to identify "key data protection issues", and suggest a draft 'Data Protection Bill'. Report and recommendations for the 'Data Protection Bill' are under scrutiny, for issue by the Govt.

Analytics

'Analytics' refers to the processes and techniques of data analysis, for generating knowledge and intelligence for strategic 'Decision Making'. 'Business Analytics' focuses on sophisticated information technologies to offer data-driven insights, for improved decision making. Organisations simply don't have enough people who can manage, manipulate and analyse the data that they accumulate.

Data is now stored in a variety of architectures, both on and off-premises. Some of that data is under the direct control of the organization. When data exists in silos, a single version of the truth is harder to come by. Organisations store, collect and process data to support specific objectives. However, they generally do not conceive innovative secondary usage, when they originally collect the data. Analytics can do much more than contribute to controlling financial risk. It can experiment faster, explore more scenarios, and be fact-driven to augment human intuition and intellect. This can support today's business, which are operating in an increasingly complex environment.

Data Analytics is the key to derive insights and value from data deluge, and has the ability to stay agile in a world of flux, with a priceless competitive edge. Behavioural data with visualization can highlight buying habits, changing needs and trends in buying patterns. Today only 4% of the organisations are able to derive proper value from their data. Analytics can help companies to see patterns in their data that enable them to predict issues and triggers, before they happen instead of being forced' to react to them after the event.

An array of industry focused analytical solutions with objective outcomes, supported by our analytics and data science practices are:

- Identify key sources of data for analytics.
- Map the correct statistical algorithm that fits the problem area.
- Define the predictive analytical model, and validate it with historical data.
- Analyze the outcome and remove the false positives, through multiple iterations.
- Showcase the outcomes and insights, and recommend actions.

The new innovations in denomination data engineering hold the key to advanced analytics. Automation of analytics has become a necessity, in order to tackle the deluge of data-driven problems. It enables us to focus our attention on higher-value tasks, and gain operational efficiency and repeatability. CXOs should consider the entire analytic life cycle, from data ingestion to exploration, and modelling to deployment. The promise of big data analytics is the ability to find latent patterns in gigantic data stacks. Private organisations such as Facebook have become custodians of troves of data, in the last two decades. This offers both opportunities and risks, as witnessed in the recent 'Cambridge Analytical Episode' of data misuse.

Digital Technology

The dot.com boom at the beginning of this century led to the digital revolution. Digital technology is an enabler for innovation and exponential growth. Digital complacency is not acceptable, as businesses are becoming more data driven. Digital transformation is more about a journey than any destination; the endgame is uncertain as goal-posts keep moving. Skilled manpower is a challenge for growth of digital economy. Digital marketing has multi-mediums for fizz and influencer outreach, like search engines, web analytics, and social media i.e. Twitter, LinkedIn & Facebook for marketing engagements. Futuristic, dynamic digital technology space, is moving us to new horizons, set to empower and ease our life.

The digital onset has changed our everyday lives, bringing in new levels of connectivity and convenience. We believe that even greater more fundamental changes await us, in the digital universe. Our digital journey will extend deep into the organization, to progressively cover additional functions. Users are consuming an average of 4GB data a month on everything from entertainment to shopping. By next 5 years, there will be over 600 million Indians with smart phones, each consuming similar content and transacting digitally.

Digital transformation is fundamental in any effort to create a differentiator for the business, and in the process helps carve out a leadership position for itself. The new technologies have made occupational skills more demanding and short-lived. As a society to benefit from the demographic dividends, India needs to urgently take to skill-building. Digitization is transforming business and supporting new business models. Data analysts will help use data with external information from third-party providers and social networks; to decipher, organize and interpret it.

Businesses that do not stay ahead of the curve will fall behind.

We have all joined the digital bandwagon even before we consciously realized it, because the process has been smooth. In today's hyper-competitive business environment, innovation and digital disruption are the norm rather than an exception. Our digital age economies across the globe are extremely intertwined, and power rests in the hands of consumers. In a majority of cases consumers are producers and co-creators as well.

To thrive in the digital economy, we need to anticipate disruption. Digital disruption allows us to unlock scale with a lean organization set up, and provide an integrated solution. The emergence of digital platforms is disrupting the traditional notion of industry. The digital economy is making employment redundant, by creating a rental labour market. Progressively, every job with predictable routines could be automated. The disruptive digital platforms are nudging people to become entrepreneurs, by making it difficult for them to find regular jobs.

Digital is all about connecting customers, employees, and machines. Digital is not a special entity, but the core of utility. Businesses today continually direct efforts to leverage existing technologies, introduce new technology and provide newer avenues to help customers embrace the digital way of life. Protecting data across mobile and connected devices is key to successful security. Digital transformation isn't only about technology; it's about marrying the power of technology with the right organisational mindset – one that is willing to embrace the change to drive organisational excellence.

The key areas, while playing the digital game are partnerships. Entertainment media companies are the leaders in the digital space. Digital transformation, processes, products, systems and gadgets, are now a $2 trillion catchphrase. Some companies are even born digital like Google's and Amazon, while few become digital like GE and Burberry's etc.

Digital transformation is about leveraging technology to uplift user experience across the value chain; fine balance between technology values and consumer needs. User has adjusted well to new digital banking touch points. 'Digital Futurist' has become a new corporate designation. A panoramic view of various digital marketing mediums that businesses can use for escalating growth, will give deep insights into the art and science of search engine marketing, social media marketing, online PR, and influencer marketing.

Digital marketing strategy covers a panoramic view, of various digital marketing mediums, for escalating growth, like:

- Web Analytics
- Social Media Strategy
- Twitter Marketing
- LinkedIn Marketing
- Influencer Outreach.

The digital world created giant monopolies. Facebook acquired 'WhatsApp' in 2014. See, where it has reached today. Google buys upcoming firms every month. Behavioural data helps to understand buying habits, changing needs, and predicts trends in buying patterns and create sophisticated, tailor made messages for specific moments and events to stand out of the clutter. Thought leadership will become a valuable driver of trust, among buyers.

Healthcare is another area, where digital technologies are making changes in both operations and the business model. 'Wearable Sensors' are allowing consumers to monitor and share data about their fitness and post-treatment recoveries. Now hospitals are reaching out to patients, instead of just waiting for them to arrive. Medial knowledge, experience and expertise are being collected in huge data systems, and algorithms are identifying diseases and recommending treatments. Sensors and robotics are taking over operations, and organs are being printed by bio-printers.

In the digital world, military capability is rapidly shifting from visible to the invisible, from hardware to software, from atoms to bits. In the virtual world, there are few rules of the game, little way of assessing your opponent's intention and capabilities, and no real clues. Technology will play a significant role in shaping the global economies in the coming decades. Digital governance is good governance; digital delivery is faster delivery; and digital monitoring is effective monitoring.

PM Modi considers "Digital India" as a major economic growth driver, and therefore it is strategically listed among the top priorities of the Government, to transform India into a digitally empowered and knowledge society. Convergence between connectivity, knowledge and economy will transform India into a modern 21st century nation. Given the high potential of digital technologies, it should be possible to double the size of Indian digital economy every year, for the next few years. What kind of entrepreneurial and policy measures are required to make digitization affordable and inclusive? How can digital India be secured against disruptions?

Artificial Intelligence (AI)

Definition of Artificial Intelligence (AI) is 'a computer system capable of performing tasks that normally require human intelligence'. The intelligence in 'Artificial Intelligence' constitutes a combination of processing power and access to data enabling analysis of entire population of data, to identify patterns or exceptions. Artificial Intelligence' encompasses a range of technologies, from 'machine learning' to deep learning. 'Predictive analytics' is going to have a big impact on AI. Defining Al in terms of the tasks is what humans do, rather than how humans think.

AI is how to make machines mimic human thinking and action. AI can process billions of data points, to arrive at an efficient decision in the blink of an eye. Of course the contextual, emotional, creative and intuitive aspects of decision making will remain the prerogative of human judgment, which will be hard to replace. The merging of man-machine is out, to create a powerful workforce. 'Machine learning' relates to teaching machines how to learn from the past data, and create their own knowledge. AI is advancing to a level, where systems surpass human capabilities and comprehension. Should human race be worried about AI taking over the world?

Cognitive computing refers to systems that learn at scale, reason with purpose, and interact with humans naturally. Rather than being explicitly programmed, they learn and reason from their interactions and from their experiences with their environment. AI and cognitive technology are being developed to augment human intelligence to enhance and extend human capability, by embedding them in the processes, systems, products and services.

AI is the ultimate 'invisible hand', that is already at work in almost every aspect of our lives. It is too soon to tell what the full consequences of AI's role in decision making would be. It is not premature to start preparing for it. Machines are not even close to intelligence, since they can't compete with the human brain. Artificial Intelligence will probably become one of the biggest wealth-creating sectors in this century.

The age of artificial intelligence is creating an invisible revolution, and is changing the nature of work. As every interaction is becoming digital, organisations must set the pace for transformation and for AI to complement rather than disrupt work. AI will augment, not displace jobs. Leaders need soft skills to create new AI led innovations, adaptability, and continuous learning. AI will augment human ingenuity. Technology has its upsides like improving access to services, and down sides like replacing person to person interactions. We need to lay foundation for an AI-centric, future ready work force.

The AI revolution is leveraging chat bots to improving customer and stakeholder interactions, to reduce menial tasks for frontline workers as well as providing greater insights for workers to make better decisions. AI is driving an invisible revolution within the workplace. Sudden acceleration of automation in banking, finance, healthcare, risk and fraud detection sectors, have considerably accelerated the adoption of new age technologies.

'Machine learning' in computer vision, speech recognition, image recognition, among others are considered different branches of AI. The merging of man-machine is to create a powerful combined force. A company called Neuralink is in the process of developing devices that can connect direct to the human brain. "It will just be a chip in our brain, like a smart phone in our hands." With the supercomputing power of AI and chips embedded in our brains, superhuman qualities can be acquired by integrating the best of what man and machine together can accomplish.

AI will transform all major industries like the present healthcare, education, transportation, retail, communications and agriculture etc. AI and robotics are replacing, and will continue to replace, traditional jobs. Over the next 20 years 30% to 50% of jobs are at risk due to AI and technological displacement. AI is advancing to a level where systems become so intelligent, that they surpass human capabilities and comprehension.

Disease diagnosis will become faster and more reliable, allowing people to live longer and healthier lives. Risk management has one of the largest opportunities for incorporating and strengthening the use of AI. AI is also being used to reduce the strain of regulatory compliance and to overhaul the way banks do theist routine tasks or detect financial crimes and frauds. Driverless vehicles, smarter public transport, and public space design will improve urban quality of life. Simultaneous translation software will increase opportunities for global collaboration, by removing language barriers. Chinese talk of demise of human translators by 2029.

Corporates can harness the capabilities of AI and data analytics, to aid their decision-making processes and improve their work efficiencies. Jobs will be redesigned around the AI and data analytic ecosystems. Systems will be reconfigured or replaced, so that data can flow seamlessly across platforms. This improvement is not incremental, but transformative. AI is the future. Google, Microsoft, Amazon and Apple are all making big bets on AI.

As per the World Economic Forum report, about five million jobs will be lost to robots and automation by next year. AI has phenomenal power to substitute repetitive tasks that require sequential logic. Future networks must have enough bandwidth, be automated, self optimizing and self repairing. AI will allow network functions to be placed on auto-pilot. The US already has about 78,000 AI researchers; China about half that number. This is an important indicator of technological development.

Recently, the 'Competition Commission of India' (CCI) imposed a hefty penalty on Google for abusing its dominant position in the 'online search' market. The company was accused of promoting its own verticals, at the expense of its rivals. In future, competition policy will have to face the challenges of AI and big data. Since Google is a leading AI company, this occasion may be used to think about these broader sectoral challenges also.

UK Govt. has set up a 'AI Council' to champion responsible adoption of the technology. £1 billion annual investment and research grants are to ensure that public engagement is integrated into a project strategy. UK is dedicating more resources to engage the public about advantages that AI will bring about. British foresee a potential public backlash, similar to that provoked by genetically modified crops. McKinsey estimates that AI could add $13 trillion a year to the global economy by 2030. If people choose otherwise, opting out of AI may become harder in some cases. Failure to communicate the advantages could produce wide spread public hostility. Leaving the public behind could abandon them, on the other side of the fence.

The recent global summit on Artificial Intelligence – 'Responsible AI for Social Empowerment' (RAISE), 2020, charted a course on use of

AI for social transformation, inclusion and empowerment in areas like healthcare, education, agriculture and smart mobility.

Internet of Things

Internet of Things (IoT) connects everything from door locks, lighting, TV, oven, water heater and other devices like traffic control signals with a vast network of physical world of sensors and devices, connected through internet. IoT is a fundamental shift for creating innovative and intelligent products and services, bridging the gap between digital and physical world. Smart machines are better than humans at accurately and consistently capturing and communicating data. IoT solutions have improved asset utilization, labour productivity and our everyday lives.

The Internet of Things (IoT) is the concept of using built-in sensors to gather data and take action across a network. IoT promises to make the environment, homes, offices and vehicles smarter, more measurable and chattier. IoT generates vast amounts of data from sensors attached to things. It's a notable driver of big data assignments, because it facilitates creation and analysis of vast data sets. IoT is a major engine for creating innovative and intelligent products and services.

Data generated by sensors will strengthen systems and supply chains. 'Wearable human devices' will help monitor our exercise, sleep and other health habits. 'Patient monitoring devices' maintain electronic records and operate other smart life-saving accessories. Connecting more things to the internet has the potential to increase efficiency, lift productivity, reduce waste and fuel economic growth. Once IoT starts supporting billions of connections among cars, trains, factories and hospitals, the operating costs will sky rocket unless network can be maintained with little human intervention. Fully networked IoT could add up to $11 trillion to global economy by 2025, with 100 billion connected devices.

Planning close synergy between the 'Digital India' programme and the IoT, the IoT will be part of the broadband highway that will deliver a wide range of e-governance and citizen services to all corners of the country, with Industrial IoT as an enabler of 'Manufacturing 4.0'. Application of deep analytics software can turn massive data into powerful insights and intelligence.

IoT is bridging the gap between the digital and the physical world. It offers new sources of data and business operating models that can boost productivity in a variety of industries. With the International Data Corporation (IDC) putting the worldwide spending on IoT as USD 1.10 trillion in 2021, IoT is a big thing. According to IDC, IoT hardware will be the largest technology category, followed by services, software and connectivity.

Robot Process Automation

Robotic Process Automation (RPA) technology mimics human actions performing simple rule based processes. It takes the robot out of the human. Progressively, every job with predictable routines could be automated. Robot mimics a process, rather than analysing data. Works faster, non-stop, more accurate, and is scalable. Businesses talk of automation of the factory floor and the call centres replacing people with robots and intelligent tools that can perform tasks with increased efficiency and at reduced costs.

The growing reach of industrial robotics is a modern phenomenon. In the early 20th century, the concept of robots in society found its way into science fiction, when Rossum's Universal Robots premiered in Prague in 1921. The play told the story of sentient Robots that rose up together and killed their human masters. George Charles Devol is widely recognised as the father of robotics for having invented the 'Unimate', the world's first industrial robot in 1954. 'Unimate' was installed in General Motors's auto manufacturing plant in the early 1960's, and the robot was designed specifically for die-casting and spot welding. Seeing the early success, Ford was quick to come on board, and other car manufactures similarly followed suit.

RPA is the natural evolution of labour arbitrage. The advantage that RPA has over traditional automation techniques is that they rely on back-end automation, requiring massive IT transformation, huge investments, and complex decision making. The robotics boom in the car manufacturing industry marked the first of the three distinct phases, in industrial robotics, which are:

- 1960-1979 – Basic industrial labour replacement robots.
- 1980-1999 – Computerised robotics, entering the workplace.
- 2000 to Present – IT driven smart robots, allowing mass automation.

Robotics and artificial intelligence are set to eliminate many tasks and roles, and change the rest. Robots will take over the repetitive jobs, including routine decision making. Both organizations and individuals have to be ready to face fundamental changes in the workplace. Comprehensive up-skilling would be essential to boost Indian manufacturing. Often people only view automation through the lens of being a means to drive down the cost of labour. To come out as a standardised product of a certain quality, automation is critical. It allows you to adjust the machine better; you can ensure it runs properly to the correct specifications and quality.

Yes, there will be some job displacements, but those will be offset by the newer higher-skilled jobs, that the new workplace would require. McKinsey Global Institute sums it up best: "More occupations will change than will be automated away. This is an important differentiation, as it paints a picture supported by the IFR's experience and picture of a future, in which robots and humans will work together, each doing what each does best.

The spectrum of automation expands from simple rule-based automation to advanced cognitive and artificial intelligence automation. The ability to automate depends on three factors: the type of input it can read; the amount of data it can process; and the nature of output it can generate. Will robotics take away manufacturing jobs and destroy the economy, or will they free up blue collar workers to work in higher-end industries? Economist Andrew McAfee, writes, "We are facing a time when machines will replace people for most of the jobs in the current economy, and I believe it will come not in the crazy too distant future." Accenture suggests that the potential of automation can increase labour productivity by 40% by 2035, especially in the 12 global large developed economies.

Leaders shouldn't fail to align their operating model with their new strategy'. Employees in organisations will soon be outnumbered by robots. Change is coming, and it's going to become inevitable for organisations to adopt. A report by the 'Institute for Robotics Process Automation' predicts that over 100 million existing FTEs could be replaced by automation software in the next decade. The 'International Federation of Robotics' (IFR) observes: "Robots increase productivity and competitiveness. Used effectively, they enable companies to become or remain competitive. This is particularly important for small-to-medium sized (SME) businesses that are the backbone of both developed and developing countries' economies. It also enables large companies to increase their competitiveness, through faster product development and delivery." The maturity of technology makes it viable for drones to carry payloads for last mile terrestrial deliveries especially in remote areas, at costs lower than through surface transport. Robots are also slowly taking over large warehouses.

Today, we are in the midst of a changing landscape, where advances in robotics and automation are finding their way into the "softer" service areas, not just manufacturing. Leaps in artificial intelligence and machine learning have seen virtual assistants deployed in various retail products, like the Amazon's Echo. Commercial enterprises are employing chat bots to assist and guide people through their online shopping experience. In Japan, there is already a hotel that has introduced a responsive robot that can check people in, brief and escort them to their rooms. It can speak to the guests in either Japanese or

English language, and can even field some basic questions.

As per the World Economic Forum report, about five million jobs have already been lost to robots and automation by 2020. AI has phenomenal power to substitute repetitive tasks that require sequential logic. Some of the jobs that could be outsourced to AI powered digital assistants include entering timesheets, scheduling calendars and routine accounting, billing and HR tasks. By 2025, Robots would have taken up over 30% of the present jobs. In terms of dollar value, the robotics sector is expected to rise to $67 billion by 2025.

Block Chain

Blockchain came up in 2009, as a secure distributed ledger system to record financial transactions of its members. Blockchain registers every single transaction, may be financial, hospital records, or government data. It is an internet rotary service that updates transactions, making them immutable. Ledger can record ownership transfer of any type of assets, claims or obligations of all assets from property to commodities. Understanding the application of technologies, such as block chain and machine learning are essential. DLT (Distributed Ledger Technology) and block chain have removed the need for multiple data bases, for records that are accessible to anyone; & provide a perfect audit-trail for each transaction.

Blockchain and related trusts with enhancing technologies are poised to redefine the industry, and how consumers purchase, insure and use vehicles. Blockchain adopted by a consortium of life insurers is trying to eliminate fraud at the time of 'on boarding' a policy holder. It is using chat bots for customers, employees and distributors, plus using predictive algorithms to anticipate and handle volume spikes.

Block chains have the potential to facilitate certain aspects of the AI implementation. Block chains can provide a secure environment for big data owners: A new technology to create new community centric business models and crypto-currencies with a block chain database.

The world is excited about the potential of block chain to change how the internet is governed. There are questions about scalability, as Internet of Things (IoT) and block chain generate huge data as they scale up. Start-ups in this space are all set to invest in block chain technology, and develop a distributed ledger system among themselves. These make sense, when the governments also start getting all their records and documents on a similar platform. Blockchain can make the reconciliation of accounts of government efficient and seamless. We don't actually need to do any reconciliation anymore. This improvement is not incremental, but transformative. Fourth generation blockchain platforms will enable a secure end-to-end transaction concluded in under two seconds, irrespective of the broadband speed.

India is in the early stages of a land-title registry system, on top of which you can tokenize ownership of real estate. People can potentially invest in tiny pieces of real estate and hopefully, an internet notary service will update transaction ledgers, making them immutable. Ledger can record ownership transfer of any type of assets, claims or obligations from property to commodities. Today, blockchain and cognitive technologies are helping reshape industries, in domains as varied as finance, healthcare, and government.

Blockchain is the technology underpinning the Bitcoin and other crypto currencies. One of the largest scams in recent times was the 'Bitcoin scam', worth over Rs 1,500 crores, perpetrated by Amit Bharadwaj. There has been a Cambrian explosion in terms of organisations trying to solve serious real world problems, using Blockcahin technology. NITI Aayog, the government of India's 'Think Tank', is firmly behind the blockchain technology for tamper-proof land records, verifiable higher education certificates, trade finance and so on. Of course, there is a dearth of good blockchain developers and strategists in India.

New community centric business models are creating block chain databases. Direct exchanges are not feasible. A huge diversity of cons help monetise all assets. Assets are referred to as digital coins, accessible through a wallet on Smartphone. User can buy, sell or transfer tokens. Transactions are real time, and do not involve middleman. They are recorded on the block chain and are universally visible transactions, executable across the globe. In April 2018, 22 countries have created a 'European Blockchain Partnership'. Ruler of Dubai has also launched 'UAE Block chain Strategy 2021'. It has announced a 'Dubai Blockchain Business Registry Project', for providing secure end to end transactions. To stay ahead of the curve and explore opportunities, Telangana Govt. has already announced the formation of India's first blockchain district, in partnership with Tech Mahindra.

Integration and Impact of Emerging Technologies

The first industrial revolution utilised water and steam power for mechanizing production. During second industrial revolution, application of power was more with the objective to obtain mass production. During third industrial revolution, industrial automation was introduced which involved vast application of Electronics and Information Technology. The fourth industrial revolution, termed as 'Industry 4.0', is empowered by a wide range of digital technologies, e.g. Artificial Intelligence, Machine-Learning, Advanced Robotics and automation, and including new materials like Graphene and advances in genetics and sensors etc.

The new technologies are transforming the way businesses operate today. Identifying the strategic benefits of the proposed technologies is crucial. Adopting organisation-wide new technology is a high priority. The application of a new technology is often one of the organisation's most significant business risks. The core of any successful business transformation is alignment with the overall organisational strategy, and the development of a robust business case.

Technology on its own is never the answer to any question. Effective use of technology requires a rigour and robustness of processes. It is always the enabler for streamlining and standardisation of the processes, across multiple geographies. Technology provides data, but people are required to exercise judgement and provide insight, to turn data into relevant information. The failure to use technology's benefits will leave organisations vulnerable. The pace of change of technology is such that we cannot foresee tomorrow. Today, every element of an organisation's business model is impacted by cognitive sciences, artificial intelligence, virtual reality, and robotics. Organisations will need to balance multiple competing priorities to navigate through challenging times of integrating new technologies and making optimal use of opportunities. We require internal partnership with concerned departments like finance etc, for the success of any robotic process automation.

There are three principal approaches in Industrial 4.0 concept, namely 'Horizontal Integration', 'Vertical Integration' and 'Integrated Digital Engineering'. Horizontal Integration' refers to integration of different information systems, applied principally for production planning and process control. 'Vertical Integration' refers to integration of information at different hierarchical levels, which allow preventive actions to avoid any defect. 'Integrated Digital Engineering' enables the collection and exchange of production data, throughout the entire chain involved. Industry 4.0 is focussed on creating intelligent products, processes and procedures that lead to ubiquitous connectivity of people, things and machines. The vision of industry 4.0 is likely to be adopted worldwide, and it might influence other corporate initiatives and cooperative efforts also.

Technology integration must be in harmony with a company's capabilities and its local culture and conditions. Advances in material science, information technology, electronics, computer science etc. have enabled the technological bases of many industries change rapidly and unpredictably, causing a paradigm shift in application of technology. Product life cycles have shortened dramatically, forcing companies to develop and commercialize new technologies faster than ever. Therefore, it is of high importance how the company's processes are rapidly and efficiently translating its R&D efforts, into products that satisfy the market's needs. Superior technology integration is the key to achieving superior R&D, productivity, speed, and products. Product life cycles during the last three decades have shortened dramatically, forcing companies to develop and commercialize new technologies and products faster than ever.

The sole purpose of technology is to simply amplify and magnify the human ingenuity. Technology has impacted diverse industries, in myriad ways. By approaching workforce challenges holistically rather than mechanically, companies will be able to position themselves most effectively for the disruptions they anticipate. Technology needs to be leveraged fully for achieving the required goals.

Project creation holds the success for realising vision, taking cognizance of technological breakthroughs and disruptions, and emergence of industry 4.0. Apart from the hype, start-ups have been identified as a thrust area by the government, with the aim to promote employment and strengthen the intellectual property ecosystem in India. Government of India's 'Digital India' initiative has helped country hasten technology adoption across sectors, with an enabling eco-system for futuristic technologies.

SUSTAINABILITY DEVELOPMENT

Sustainability

Sustainability is traditionally defined, as the capacity of an eco-system to endure. Exploiting the carrying capacity of the planet wantonly impoverishes future generations. The word "wantonly" is critical, because you could add to future capital by innovating new models of production and consumption. The capacity depends on the degree of human ingenuity and innovation. This is what has enabled homo-sapiens to thrive on this planet and take gigantic leaps, despite monumental natural handicaps.

Sustainable growth refers to creating share holder and societal value, while reducing the environmental footprints along the value chain. Sustainability is the path to business growth, the new lingua franca in the marketplace, as Indian corporates start thinking beyond. The concept of sustainable development has been transposed from the macro to the corporate dimension; in as much as a corporate entity is a productive agent of our socio-economic system, a conduit of the eventual implementation of sustainable issues and a socially responsible citizen.

The global challenges associated with sustainable development are multifaceted, involving technical, economic, social and environmental concerns. As a global society, we are living on an edge. Our approach to challenge the conventional wisdom and changing the corporate psyche is to demonstrate virtues of being ethical, transparent, equitable and responsible in our decision making, by lifting economy, Corporate Social Responsibility, Corporate Governance and environment to much higher levels.

The opportunity for 'work with purpose', to contribute to helping grow businesses and organisations in sustainable economies in a meaningful way, becomes more important. i.e. from contributing to the effective management of risk, helping organisations understand the implications of emerging data in sustainable decision making, managing regulatory challenges with greater efficiency, contributing to measuring and reporting on sustainability initiatives, and finally helping deliver better service outcomes.

The sustainability trailblazers are at the heart of performance management in the organisations. They play a key role in establishing frameworks that capture, evaluate and report on the activities that truly drive value, and in ways that are much more transparent and meaningful to the outside world. They will transform accounting fit for a multi-capital world, and see emerging opportunities with better external disclosures to ever-growing stakeholder groups. They understand that aligning the pursuit of profit with the pursuit of purpose is integral to building sustainable future businesses.

Sustainability is no longer about public relations or regulatory compliance; it is about saving costs and increasing profits. To be sustainable, sustainability must make money. The sustainability movement began with concerns over depletion of natural resources and contamination of the environment. It has now matured into a quest for disruptive innovation with bigger margins. Society is demanding that companies, both public and private, serve a social purpose. To prosper over time, every company must not only deliver financial performance, but also show how it makes a positive contribution to the society.

As we move further into the 21st century, our expectations have soared to new heights, and we are looking for a cascade of engineering advancements, that will enable us to face the challenges of accelerated nation building through sustainable development. The biggest challenge today before the engineers is to see how best development can take place with the least carbon footprints, creating environment friendly, ecologically appropriate, energy saving developmental options, and not only be Sustainable for the present generation but also be sustainable for the coming generations down the line.

The World Federation of Engineering Organisations (WFEO) submission to the 'Earth Summit' in 1992 stated that; "Engineers have the potential and the duty to be a major influence in the achievement of the primary goals of the future: a sustainable habitat for all life, and one that continues to allow mankind to achieve his potential and to enjoy the process of living. The council acknowledged the leadership role that the engineering profession must play in attainment of sustainable development. Engineers have to advance the profession of engineering by providing leadership, in the sustainable use of earth's resources.

Sustainable Development Goals

The United Nations 17 Sustainable Development Goals (SDGs), a framework for all countries to achieve by 2030, set out the building blocks of a new type of inclusive prosperity creation. Across the 17 SDGs, and the 169 targets of which they are composed, of, are a range of interconnected economic, social and environmental issues. They provide government, businesses and civil society a universal roadmap to tackle urgent challenges, to meaningfully engage with emerging risks and discover new opportunities for creating value.

The historic SDGs adopted in September 2015 by the governments of the world, provide a template for best corporate practices in a new phase of global capitalism. It is now incumbent upon corporate boards to include, within the due care parameters of their fiduciary duties, reasonable measures to align corporate vision and mission with the SDGs, as materially relevant to the business of the enterprise. The SDGs are grandiose goals for humanity to provide for the sustainability of our well being, by protecting our planetary home from degradation and providing all people with higher standards of living.

The sustainability narrative has grown to include broader perspectives, from being environment friendly to fair labour practices, from ethical mining and sourcing to replenishment and recycling of natural resources. Cross-sector collaboration will be necessary for their implementation. Each goal contains complexities and its implementation demands activation of causal systems. No one company can, on its own, do much to bring us closer to national goal implementation.

One of the most important aspects of the SDGs is that all recognise the critical role that business will play, alongside national governments, in achieving them. The SDGs will rely on the expertise of the engineering profession to operationalize the opportunities, build the systems for delivering the outcomes, and report on the progress made towards achieving these new prosperity creation benchmarks. Implementing strategies to deliver the SDGs will engage the engineering and finance professions at many levels, to recalibrate business and government activities. The SDGs will require both robust technical skills and sound ethical judgements that professions around the world would have to be well placed to deliver.

Technology will be the driving force of future engagements around the SDGs. New data sources will emerge to meet the demands of measurement. There is a clear role for the profession in ensuring data is reliable, and that it is communicated effectively to aid delivery of the SDGs. Better data will be a critical driver of the SDGs. Professional accountants will be the custodians of this data. Yet technology is only part of the story in building a sustainable future for the organisations. Businesses need to deploy wider capabilities beyond being digital, in the race to remain relevant. It's always about people.

In today's rapidly changing macro-economic environment, businesses are increasingly required to innovate operating models, access new markets and identify potential avenues for growth and differentiation. In this dynamic and increasingly competitive world, businesses also confront a strategic choice with respect to the adoption of the SDGs framework. One of the biggest challenges in business is to shift the dominant mindset from seeing sustainability as a source of problem, to seeing it as a source of opportunity. Until recently, most cultures in industry had a rather distant or cynical view on environmental issues and concerns, rather than a compassionate one.

Most companies are still unable to integrate sustainability into their business strategy. They either lack the capability to harness sustainability, or are willing to risk longevity for the sake of immediate gains. Most companies still do not integrate sustainability into their budgets and supply chains, and their environmental, social, and governance initiatives run parallel to their core business strategy. The best opportunities for sustainability linked value creations are available in industries, which are energy and material guzzlers and also produce the most pollutants. Mining, manufacturing, and mobility are the most obvious areas, where sustainability can be a profit centre. It is unrealistic to expect consumers to pay extra for ethical or green products.

The SDGs offer a compelling growth strategy, opening up at least $1 trillion of market opportunity for the private sector in India. This is out of the total global value of $12 trillion that could be unlocked by sustainable business models in four key areas, namely, food and agriculture, energy, cities, and health. Over 72 million new jobs could be created in India, to achieve this by 2030. Indian business leaders are already using innovative technologies and business models, to enter global goal-related markets.

Marketing and Social Media

With a billion-plus mobile phone subscribers, more than half-billion individuals on-line and nearly 300 million social media users India ranks amongst the world's largest and fastest growing digitally-enabled consumer markets. In recent years, rapid digitization, surging mobile internet penetration and affordable data have resulted in a sea change in purchase and consumption patterns. Mobiles play a significant role in driving purchase decisions. Growing concerns for safety and social issues have pushed marketing to new areas. Technology needs to be leveraged fully for achieving the required goals. Digital allows efficient customer acquisition opportunities. The markets have fundamentally shifted from 'offline' to 'on-line', as majority of consumers are even trying to avoid public places. Enormous challenges have been posed by changing consumer dynamics in marketing.

Amid the current challenges, personalization is the key and advances in technology, data, and analytics will soon allow closer contact with consumers. It is time to break the clutter to make marketing communication more relevant, for customers across multiple channels. Social media support has increased stakeholder engagement and activism, but this must be monitored and managed. The formal disclosures must be balanced against the risk. To find a new job or even a freelance gig, you need to create an online presence that backs up your resume. Most of the recruitment these days is done 'online', and it is important to use social media platforms, such as LinkedIn and Facebook to promote yourself and create your own brand.

The economic and societal benefits of this new era will not be realized, if the human side of the equation is not supported. This is uniquely important with cognitive technology, which augments human intelligence and expertise, and works collaboratively with humans. Social media has changed the nature of shareholder relationship, allowing us the potential to message a global audience at the click of a button. Social media has replaced TV and newspapers as the first source of news, and as the primary resource for marketing and propaganda. As a result, eyeballs are shifting, as is advertising. The digital age has at its forefront a new breed of entrepreneurs, who are breaking all traditional mindsets about business. Social media powers the e-commerce. Today more than half the Omni channel publicity leaders put social media on par with conventional channels.

It was social selling apps and services that made more sense for selling by small stores, rather than online market places. Social commerce is like a pipeline for small businesses and brands, to graduate and come onto market places. Indians are using voice searches to shop 'online', and e-commerce majors are investing heavily in making the technology more accessible. Amazon and major retailers are betting on 'voice supply' to reach out to AI consumers.

Today, of the top 100 global economic entities, 70 are corporates and only 30 are countries. The corporates are no longer sheer economic entities, but engines of social transformation and sustainable growth. Today, a company's brand value stems from public perception of the difference it makes in a society. The pressures facing business today are with trade policies shifting and globalization crumbling; the democratic model is losing its sheen. Enterprise transformation led by marketing is increasingly becoming foundational to any brand's digital transformation story, wherein agile data driven decision-making replaces bureaucracy.

ENGINEERING AS A PROFESSION – THE FUTURE PATH

Corporate Board and Governance

The board of directors is the principal agent of the enterprise for risk-taking and commercial judgment, within a company. Effective boards have a balance of well-chosen competent executive and independent directors, who provide a cohesive working group to shape the destiny of the company, safeguard it's interests, and ensure profitable performance. The composition of the 'Diversity Matrix' of a well performing board needs balanced diversity of knowledge, skills, and perspectives, apart from ethical and gender diversity.

Corporate boards are the most important institutions in capitalism. The key performance indicator (KPI) for the board finally reflects the sustained financial health of the company. Boards face the problem of where and how to draw the line between direction which is the task of the board, and management which is the task of the executive. The board has to discipline itself to deal with every issue, and both prescribe and proscribe through a policy. Fair and consistent disclosure and transparency are adequately reflected in today's international 'Integrated Performance Reporting System'. It is time, it becomes mandatory for all companies in India.

Board of Directors are involved in directing and leading their organisation towards a digital transformation, ever wary of the not inconsiderable risk scenarios along the way. Deloitte puts it this way: "Boards play a critical role in the digital transformation journey, by bringing expertise, judgement, healthy scepticism, and concern for long-term value." The boards require to be digitally literate and provide leadership for skills and competencies to properly govern digital transformational initiatives. The non-linear unconstrained thinking and a clear long term strategy are needed to take right risks, at the right time. To leverage full power, corporates need to become digitally relevant and flexible to change.

Boards act as the lead umbrella for governing and managing a successful organisation. Business model is based on governance, which starts with the organisation's vision and mission, and consists of an oversight by the board of directors over enterprise planning & operations. Corporate Governance is the domain of board of directors and refers to framework of rules & practices, by which board overseas strategy setting and leads the organisation. Strategy setting is the process by which executives manage and articulate a high level plan, for achieving goals consistent with organisation's mission.

Strategic planning and performance management contribute significantly to the survival and success of all businesses and organisations. Corporate governance tops the list of competency areas, where specialist skills will be most important, and it is second on the list of areas where vital skills are missing. Globalisation will require both local and international knowledge of emerging trends in business, technology, and society with frameworks and best practices of corporate governance, risk management, diverse cultures and business practices.

The responsibility of the board of directors has been on the corporate agenda, as a matter of concern for decades. The directors are expected to collectively devise strategy for the organisation, and monitor effectiveness of the company's performance. The board is a vital pillar of the robust corporate governance framework. They have to provide shareholders return on investments on a regular basis, and yet assure long term sustainability of the organisation. An organisation is only as good, as those who lead it. It is the corporate board who defines the vision, strategy and goals, manages the risks, sets the tone, and creates the culture and ethics of the organisation.

Calls for more guidance and regulation will increasingly come from a broad range of external stakeholders. Over the next decade, governance and risk management will focus ever more closely on compliance and procedures, which will become more holistic, formalised and integrated. Governance and risk structures, processes and relationships will become increasingly more challenging, from technical and ethical aspects. Risks associated with disruptive innovations are always high on the board agenda. They require a coherent strategy, underpinning data, security, and privacy.

The board of directors and board committees are where all company policies are made and leaders nominated. You need a set of ethical core values, that can be applied anywhere in the world. Integrated reporting and sustainability are going to be critical, as far as corporate governance is concerned. We need strategic thinkers; people who are forward-looking. It's not just about behaving ethically, but also demonstrating it.

The major business supply chains had broadly relied on global inter-connections, to improve profit-margins. With disturbed geo-politics, the supply chains now need to be revamped; be shorter, risk resilient, agile, and transparent with end to end operational visibility. We need to regularly use 'Network Analytics', to diagnose the relative fragility and under-lying vulnerabilities of these supply chains.

Today, large businesses are exposed to real-time monitoring by the media and the internet. Corporates are in an early stage of data and technology led sustainability revolution. Digitisation and emerging technologies are becoming an integral function of our management process. Digitisation, data, and cyber security are listed as our top risks today. We need strategies to enable us to prosper in different set of circumstances, markets and environments. How to ensure that legal, regulatory and governance framework remain aligned with growing diversity, changing operational requirements and new business models, without inhibiting innovation?

In today's global marketplace, enterprises are confronted by a growing number of risks from internal and external factors from employees to suppliers, data breaches, natural disasters, and more traditional controls and safeguard are being stretched to the limit due to longer and more complex supply chains and increasingly onerous regulations. Security cannot be an afterthought any more. They should adopt holistic, process oriented security solutions that enable end to end management, rather than any piece-meal implementation. Holistic reporting encompasses financial and non-financial reporting and risks. The professionals will need to meet the evolving needs of increasingly broad range of non-financial stakeholders, both inside and outside the business.

The Institution of Engineers (India)

The Institution of Engineers (India), (IEI) featuring all major disciplines of engineering with excellence in service domain for technical education and engineering practice, was established in the year 1920. The Institution was granted the Royal Charter on 9 September 1935. The objects and purposes of the Charter focus on "to promote the general advancement of engineering and engineering sciences and their applications in India, and to facilitate the exchange of information and ideas on those subjects, amongst the members of and persons attached to the Institution". The Institution can look back with great sense of pride on the achievements of the last century. As the Institution enters the next century, it needs to focus on the future direction, in which the engineering profession should move.

A work begun by IEI in 1920 has by now grown into a global presence; but it still has its finest years ahead of it. The Institution moves into its next century, with a new sense of purpose, to rise to the enormous challenges of high quality engineering standards. IEI is driven by 'Mission', not by 'profits'. It will continue to lead the profession, by developing timely and relevant knowledge and career path guidelines.

IEI, being the apex body of engineers in India, is committed for holistic development of the country and for that to fulfil the requirement of producing highly technical skilled manpower. Being the largest professional body of engineers in the country, IEI has always taken up a commensurate role for meeting the country's engineering needs. The key point for IEI is to raise the potential of the engineering profession, and to improve the quality of life for the society. Because of the exponential rate of technological growth, the current engineering practices are never adequate to provide full value by the Engineering discipline, as required for sustainable development. Acting as a knowledge engineering society, this role becomes of paramount importance for the Institution.

Many global priorities will compete for the government and public attention, over the next decade. Engineering leaders must equip themselves to educate and influence the decision makers, and influence the critical choices at corporate board and society levels. The complexity of advanced technologies and the multiple scales at which systems now interact, require business management and engineers along with social scientists, economists and other professionals to collaborate, in developing multidisciplinary solutions. Engineering must be at the forefront of implementing system approaches, across these multi-scale systems. A global spirit of collaboration and partnership is essential, for achieving effective global vision and mission. Engineering profession will need to develop and embrace partnerships, among industry, government, and academia.

Increased regulation and stronger governance will have great impact on the engineering profession, during the next decade. The complexity, variety and interconnectedness of the underlying factors, make it impossible to anticipate exactly how these trends will evolve. If professional engineers are to thrive and add value in the future, they will need to develop the skills and competencies that organisations and situations demand. Those in and around the engineering profession, must plan for the expected and the unexpected, the predictable and the unpredictable.

The systems and processes for lifelong education are needed to help engineers stay current with technological advances, and increasingly complex technical systems and applications. There is also an urgent need for the engineering workforce to be connected with national and global sustainable development, for engineering and societal growth. Engineers must accept a new imperative to take a leadership role in political, social, industrial, professional and cultural arenas also, to bring the engineer's perspective for a wider attention. Diverse pathways are needed for engineering leaders, that encourage diversity in the profession, and still attract and retain the best and the brightest people.

The intention is to bring together the engineering fraternity of the country, to discuss challenging contemporary corporate and social issues from an engineering perspective. Engineering innovation is a philosophy that leverages the emergence of a new technology, or a combination of technologies to offer worthwhile benefits. With the advancement of innovation in Engineering and Technology, these fields have become more sophisticated and interdisciplinary in nature. In a dynamic business environment, constant innovation is essential, to match such evolving challenges.

Engineers have to be trained as the main drivers for change that will have the most impact on the profession, plus the technical, ethical and interpersonal skills and competencies, required for the future by the profession. IEI must continually advise the central Government departments and concerned national higher technology educational regulating authorities, about emerging technologies and the required changes in engineering college syllabi's, including other technology integration concerns.

IEI to collect globally best engineering case studies, practices, and bench marks to raise the quality level of engineering profession in India. Achieving global vision for engineering will require professional organisations and leaders to make a number of significant changes for the engineering fraternity. Inspiration is one of the basic factors for idea generation and innovation. Professional Ethics can be viewed as part of a critical path for the engineering profession, as it is rightly said that "Engineers build the Nation". Knowledge, skills and ethics are three important basic parameters for a professional engineer. IEI Should enhance the capabilities of all IEI units, like the 'Engineering Staff College of India', state/ Local Centres of the Institution, and at the same time initiate new activities that will benefit members and engineering students in a synergistic manner.

The clarion call of our Prime Minister on "Swachh Bharat", "Make in India", "Digital India", "Bharatmala Project", 'AtmaNirbhar Bharat' and other such national programmes is to develop indigenous environment-friendly technology and engineering practices. Engineers form the backbone of technology and infrastructure development of the country. Government departments, R&D organisations, industries, etc. have to be strengthened through planning and conducting regular collaborative technical activities of national importance simultaneously. Our collective efforts in this direction would provide larger role and recognition of engineers.

Engineers as Professionals

The engineers have to succeed in convincing stakeholders that engineering and technology can greatly help in solving many of our current issues, and also provide appropriate pathways through society-centred technology initiatives and multi-skilling programmes. We need to create infrastructure for development and create more jobs, without losing control due to automation, robotics and artificial intelligence. The engineering profession should continue to be the leader in the multi-disciplinary field, which is attempting to address the greatest inequality in the world i.e. quality of life. Engineers with their background, experience and role are most qualified to retain this key role. Most of the India's 'Public Sector organisation' (PSUs) today, are headed by engineers.

The present links of engineers with the community are indirect, through clients and employers, leading to inadequate recognition of engineer's role. Engineers need strong communications skills and ability to deal with large, complex and ill-defined systems, with a well-developed ethical stance. Engineers must be knowledgeable, understanding and sympathetic to the needs of other disciplines they work with, and the communities they serve. Failure to do so will make governments and funding agencies, to pass over this leading role to professionals of other disciplines. Most engineering professionals lack broad knowledge of their business or organisation, the environment it operates in and wider local and global trends affecting it; it impedes their capacity to take a overall rounded view, and reduces their ability to communicate effectively with other stakeholders, both inside and outside the business.

Forward thinking engineers need to grasp this reality and see opportunities for influencing the heart of the organisation. See how available information can provide strategic insight in real time, and have effective processes in place to predict future performance in a more agile manner for quick decision making. The latest advances in technology promise significant benefits for the senior engineering professionals. The engineers who fail to take advantage of these opportunities, will be marginalised in the strategic decision making process, at the leadership table. Today, engineers are often found wanting in areas of multi-disciplined technological challenges, and management areas like corporate strategy, supply chains, and socio-economic, legal and sustainability issues.

Digitisation, multi-disciplined engineering, sustainability and good governance are the senior engineers' path for the future. To achieve this vision, a paradigm shift in engineering profession would be required. Engineers need to have a vision:

a. That while emerging technology can be a disrupter; the engineer should be able to integrate it with the system, to chart its own path.

b. Covering the attitudinal and behavioural changes required in engineers.

c. That is rooted in traditional values, but still resonates with the community.

d. To understand the practice of engineering, leading to community needs and sustainability.

e. That engineers at senior leadership role need to take on challenges of business growth and sustainability, covering technologies, socio-economic, legal and sustainability issues.

All professional engineers should plan to undergo a 2 weeks refresher updating programme as a mandatory requirement, to help maintain their principle role of planning, leading and guiding integrated corporate projects and teams, and for in depth understanding to address a whole range of issues, once every 10 years or so, covering:-

a. One week of multi-disciplined technical package, covering emerging technologies and their application.

b. One week of corporate legal, compliance, management and governance package.

c. Senior engineers with 20 to 25 years experience, should also be specially exposed to a 3 days weekend condensed programme in corporate leadership, like the 'Institute of Directors', training programme called 'Masterclass', covering Corporate Governance and related boardroom issues for the executive directors. It will cover basic knowledge of all boardroom issues including corporate Finance, Law, management, planning, performance reporting, corporate governance, sustainability and risk management.

If engineers are to take on a corporate executive leadership role in business, social, and national development, it has to pass through leading and guiding integrated teams, and addressing a whole range of issues that are fundamental to corporate concerns. At present, there is generally a lack of direct interface between engineering and other corporate disciplines like finance, HR, and marketing etc. Engineers need to broaden their interests, beyond the simple and technical, to take up the leadership roles in corporate hierarchy.

Work Force

The new technologies have made occupational skills more demanding and short-lived. To benefit from the demographic dividends, India needs to urgently take up skill-building. In order to remain globally competitive and offer products and services of a higher order of complexity, Indian companies will need to assimilate emerging technologies, and develop not only a skilled workforce but an entire ecosystem, that supports the upward thrust. As organisations transform, the new business models would emerge. Engineers would need to think more laterally about the different skill groups, varied work practices, and shifting career opportunities. The CVs of the future would be skill evident, not job-title centric.

Business leaders need to consider the following steps to create the future workforce, in which humans and intelligent machines work together, to improve productivity, innovation and growth:

a) Pivot the Workforce :

- Pivot the workforce to new business growth models. Orientate teams to support new customer experiences.
- Use automation to fuel growth by reinvesting savings, in the future workforce.
- Organize for agility. Create flexible processes: manage the workforce to support both the core and the new businesses.

b) Scale up new Skilling :

- Prioritize skills for development, to strike a balance between technical, judgemental, and social skills.
- Target 'new skilling' to cater for different levels of skills, and willingness to learn.
- Go digital, accelerate the speed and scale of effective up-skilling.

The ascent of the next generation in the profession is already happening. 'Digital Natives' bring new perspectives and different aspirations to the profession, as they enter the workforce. Their aspirations will influence the shape of careers in the profession, and how business leaders will adjust their workforce strategies, to accommodate the new generation of incoming talent.

We need an optimal combination of the present technical knowledge, skills and abilities, with the interpersonal leadership behaviours, skills and qualities for the engineering professionals of the future. Senior management would need to handle a range of emerging technologies; many will also need to be expert user of predictive analytics, big data and smart software; some will also need to focus on the inherent risks and challenges of corporate governance. Global connectivity, smart machines and new media are just some of the drivers, reshaping the nature of future work. With harmonisation of business standards, the teams may need to be multinational and culturally diverse. Being multilingual, understanding different countries and cultures, and having the interpersonal skills to work as part of or to manage diverse teams, will eventually become an important requirement from our future engineers.

Companies are not investing adequately for re-skilling their employees. As automation and robotics sweep in, the opportunities for engineers to work as reactive problem solvers will diminish. Most of the present workforce is skewed towards more traditional services, which are declining. Software engineers would be short of employment options, in this tepid market. India's outsourcing industry is also facing a crisis of identity. Most of these skills are centered around managing resources, not for creating value.

We have entered a new digital and automation age where the adoption of automation, robotics and artificial intelligence (AI) is accelerating dramatically, bringing a shift from job design to work architecture and creating an "augmented workforce", where humans work side by side with their emerging machine co-workers to drive business value. This new world of work is having a profound impact on business and societal changes. Employees need to focus on new responsibilities, rather than tasks. Consider the mundane routine tasks that consume so much of employees' time today, distracting them from their strategic responsibilities such as planning, client relationship building, or ideation.

Knowledge and Skills are the 'New Currency' of Work. The modern digital era has brought emerging technologies to the forefront, at a rapid pace, never experienced before. This has led to a growing concern from business leaders that the global workforce is not able to keep up with the current rate of change. Business of re-skilling needs to be further boosted. The companies need to re-skill their employees for greater flexibility. Human life has become like a smart phone; you have to frequently upgrade the device and download a new version of the 'OS'. There is need to effectively harness the collective intelligence of the augmented workforce.

With the advent of the fourth industrial revolution, it is expected that digitization, AI and robots will eliminate over 7 million jobs worldwide, primarily in the 'office and administrative staff', and also in the manufacturing sectors. This loss is expected to be partially offset by creation of more than 2 million new jobs in specialized technology, engineering and architecture fields. In the next 10 years, over 40% of the present jobs may totally disappear. Arranging skill development in the new technology areas will become the key to ensure the required workforce of tomorrow.

The speedy changes in communication systems and connectivity platforms are likely to transform the team working into joint projects, where team members could often come together and then disperse as their role is over. The virtual working may also enable decentralisation of these teams that can operate across different geographies. Engineers may be sought to work in different project teams simultaneously, and be rewarded for their skills, and not only because of their job title.

Training

Technology is continuously and rapidly developing. It is an ongoing process and demands continual learning. Engineering education must be given new impetus, in ways that will generate required skill in the emerging high-tech areas. Traditionally defined boundaries between technology disciplines are vanishing, and therefore engineers must have the capacity to work in interdisciplinary areas. Integration of information and emerging technologies with standard engineering education curriculum should be closely monitored and evaluated for required changes, once every 5 years or so, due to the current climate of accountability and outcome-based education.

All specialized training in engineering disciplines need to have a base of a common multi-disciplined module, covering electronics, digital techniques, data management including cloud storage, computing, artificial intelligence and management processes. Greater emphasis should be on creative problem solving and innovation, and not merely on analytical skills. Education in emerging high-tech areas should not neglect appropriate training in life sciences, as engineers often need to interact in many specialized areas like medical, agricultural, climate scientists etc, leading to the development of new technologies and products, for human and social welfare.

Proper training of engineers should also be arranged in fields such as multi-criteria decision making, basics of business management and governance, professional ethics, corporate laws, Intellectual property rights, environmental impact assessments and sustainability. Converging nano-technology, bio-technology, info-technology and cognitive science (NBIC) in conjunction with traditional engineering technologies are expected to change the way research, product manufacturing, and education are presently managed.

All professional training Institutes and industry led bodies should have 'sustainable development' criteria, included within their training course accreditation requirements. The challenge of sustainable development has profound implications for the profession, across a range of disciplines i.e. planning, environmental, accounting, design, manufacturing etc; both in the role and the practice of the professionals. Sustainable Development is a new special challenge for the engineers of the 21st century. What kind of engineers do we need to do a better job? How do we train such engineers?

Technology skills with learning habit are a virtual necessity for engineers. Real challenge in digital up-skilling lies in execution. Making an entire workforce digitally savvy, especially when the latest technologies are changing all the time, is a bit like herding last year, cats. Amazon had announced a US$ 700mn initiative to boost digital skills of its workforce.

India

India's entrepreneurial culture and demonstrated technical capacity give much cause for optimism, but it is still difficult to envisage how India's technology ecosystem can power India into the upper echelon of global value chains, on its own strength. Creating economic corridors would help businesses do "more with less", help drive efficiencies, balance the dual needs of creating customized solutions, and reaching out to a larger customer base than ever before. The real fix in reviving India's export engine lies in creating basic infrastructure, such as roads, ports, and power, as well as recent simplification of business regulations and labour law reforms. While a simpler GST structure has definitely helped exporters, especially MSMEs, the journey has only just begun and there are still miles to go, before we reach the 'Promised Land'.

The government's focus is on India's growth, and increasing employment, and most importantly skill development. With increasing productivity levels, if we want to increase employment, then our economy needs to grow faster. India is going digital. Organisations need a reboot, for as technologies change the nature of work changes. PM Modi lists 'Digital India' among the top priorities of the Govt. Indian digital economy is poised to double in size every year, for the next few years. The digitization and automation of the entire value chain will create agility, but significantly raise cyber security risks.

Rapid advances in technology mean that our youth must be primed to build sector specific skills for a global talent pool. The Indian government has already set its gears in motion, by launching various programmes like 'Make in India', and 'AtmaNirbhar Bharat', with a focus on growth. India is promoting 'start-ups' by setting up 'Technology Business Incubators' (TBIs), across the country. TBIs that nurture and mentor start ups, would be helpful to analyse the motivations of the incubators and the technical aspirations of the incubates to understand the appropriate strategic fit. How can strategic performance indicator goals be measured, through effective Key Performance Indicators (KPI)?

The government of India has built the platforms for digital disruption – 99 percent of our population has 'Aadhar', 31 crore bank accounts have opened under the 'Pradhan Mantri Jan-Dhan Yojana'; we have billion-plus mobile subscribers; almost 35-40 percent of our population uses Internet; and we have created world-class products on digital payments. 'Direct Benefit Transfer' (DBT) has been implemented across 437 government schemes. We have already created a financial management platform, for all government schemes.

CONCLUSION

The 21st century corporate focus is on technology enabled growth and development. The economic prosperity and quality of life for all depend to a great extent on the creative and innovative ability of engineers. Today, we have an economy that is non- linear, volatile, and turbulent. The technological integration, growth and sustainability are the 'corporate ways' for the future. The role of engineers in business growth is moving up from complex technology to strategic leadership.

Data is often cited as the 'new oil'. Advanced analytics is providing organizations the ability to stay agile in a world of flux, a priceless competitive edge never before enjoyed. Data is the new denomination of this competitive advantage, and a clutch of companies are leveraging information to the fullest.

Good Governance and sustainability are the ways of the corporate future. The vision of engineering profession should be to adopt and implement their concepts, as a normal part of our professional training and activities. The IEI and its affiliated engineering educational institutions need to plan and bring about the required paradigm shift for leadership, attitudinal and behavioural changes in the engineering profession.

Boards have a responsibility to effectively manage risks and opportunities related to sustainability. Today, majority of the boards are engaged in their company's sustainability efforts, to help achieve UN Sustainability Development Goals (SDGs). The 'UN's 2030 agenda for Sustainable Development', with its '17 goals' and '169 associated targets', provide a good opportunity for businesses to align their corporate strategy and goals in national and global interests.

Basic engineering education must develop engineers of tomorrow, with broad based skills of sustainability, environment, and social-sciences, along with both hard & soft leadership skills. The Institution of Engineers (India) is moving boldly into the future. It's easy for any organisation that has been successful, to rest on its laurels. The biggest risk can be complacency, which IEI can't allow.

Most engineers, no matter what their primary discipline is need to be multi-disciplined to the extent that they understand the issues involved in their application and management. It is essential that engineers become advocates of multi-disciplined engineering approach, good governance and sustainable development. The senior professional engineers should be trained for and involved in leadership, corporate governance and finance areas of business growth. The professional engineers must recognize their obligations to the global community in its widest sense, about from those to the employer, colleagues, and clients. The practicing engineers need to know the duties, requirements, and needs of corporate leadership, SDGs, corporate legislation, and governance, as never before.

Engineering opportunities are a race for relevance. Engineers have the vision, but what they need is a resolve and an effort to make it happen. Technology is not a neutral place for geo-politics. Finally, we all should check, whether the sun is on our face, and if not, turn towards it. Sir Winston Churchill said "It will be a tragedy, if the sunrise of technology, were to be the sunset of mankind".

Author's Profile

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Chairman, IGBC
Former CMD, HUDCO
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Shri Vasudevan Suresh is presently the Chairman of IGBC and had earlier served as CMD of Housing and Urban Development Corporation Ltd (HUDCO) with over 50 years of professional experience in the Housing, Infrastructure, Rural and Urban Development and Built Environment sectors. He was the member of the panel for Part 11 of National Building Code dealing with sustainable development and green buildings.

He also served as the Chairman of IGBC Policy and Advocacy Committee and played a pivotal role in reaching out to various Government departments highlighting that offering suitable policy incentives will go a long way in accelerating the adoption of green building in India. He was involved in the design and development of IGBC green building rating system for green cities and green villages.

Unequal Cities - Bringing Balance through Development of Green & Smart Cities

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BACKGROUND

It is amazing to witness how rapid urbanization is happening across the globe in general and India in particular. Today, India is on the rapid trail of urbanization and vast tracts of spaces are getting transformed into urban agglomerations. In the light of this, the need of the hour is to bring in various facets of resource conservation, water, waste, energy and environmental management into the design of the buildings and other forms of built environment. This holistic approach will go a long way in addressing ecological issues and in the process offer new growth opportunities to the stakeholders.

Building on this imperative, Indian Green Building Council (IGBC), part of Confederation of Indian Industry (CII) which was formed in 2001, with the support of all the stakeholders, has facilitated in re-introducing some of India's best ancient architectural practices and approaches in the design of the buildings. As the green building movement progressed, IGBC could also facilitate in introducing some of the innovative and futuristic green building concepts and technologies, which are ecologically superior and economically viable.

IGBC was the first certification body in the country to go beyond 'Green Buildings' and pioneered into 'Green Built Environment'. This led us to a green path to cover neighbourhood, campus, town ships and to Green cities and Green villages. Urban mobility being the connecting link for all human activities, ratings covered green urban transport infrastructure as well.

In a span of about 20 years, IGBC through its multi-pronged approach could facilitate in bringing about a paradigm shift in the way buildings are conceived and designed across various forms of built environment. This approach is appropriately matched with a corresponding green building rating system. IGBC has launched 28 Green Rating Systems for Buildings and Built Environment which are designed to address various building typologies like – residential, commercial, education, health and wellbeing, transit, industrial including logistics facilities and built environment.

As on October 2020, over 6,055 projects have adopted IGBC Green Rating systems, amounting to over 7.61 billion sq. ft. of registered green building footprint, with projects spread across the Country. IGBCs projects include cities, railway stations, schools, infrastructure projects, homes, metro rails, hospitals, etc., Today; India is one of the top 3 Countries in the world in terms of largest registered green building footprint and aspires to facilitate 10 billion sq.ft. of footprint by 2022.

Thus IGBC has been able to reach out to the city development needs for buildings and infrastructure and to make them contribute to the many sustainable development attributes and create smart, green and sustainable cities.

IGBC's approaches are fully aligned with National priorities and complement various Government initiatives including -Smart Cities Mission; Swachh Bharat Mission; AMRUT cities, PMAY. Further, IGBC is also playing a catalytic role in realizing UN's SDG goals. Moving ahead, year

2020 holds a special place to the green building movement. CII would be celebrating 125th year of its establishment and this paper will be a glowing tribute to CII's contribution to Nation building.

Each story in this paper has something to say and offer to all of us. All these stories underline how concerted and mission approach of the cities can redefine the green master planning and green policy interventions and pave way for a greener tomorrow.

HOLISTIC APPROACH IN DEVELOPMENT OF GREEN AND SMART CITIES

It is estimated that country's building stock is all set to grow 100 billion Sq ft by 2030 and here lies great opportunity for India to construct all the upcoming projects as Green Cities by design and set new global standards in design, construction and operation. Broadly, a Green City will facilitate the following (not limited to)

- Enhanced quality of life
- Efficient use of resources
- Efficient land use planning
- Efficient mobility management

In days to come, all the upcoming cities should be designed as Green Cities. This will holistically address national priorities which include conservation of natural resources, water efficiency, energy efficiency, handling of municipal waste and health & well-being of the citizens. Green Cities present an excellent opportunity to redesign and transform cities by solving critical infrastructure issues, thereby encouraging people to live more sustainably.

FOLLOWING ARE SOME OF THE FOCUS AREAS OF GREEN CITIES

Employment Opportunities: Cities, due to the economic prospects they offer, attract population from rural areas. Hence, all the upcoming Green Cities will be an important source for job creation and offer new growth opportunities for various vocations.

Walk to Work: In a Green city, concept of mixed used development will be a way of life and will significantly improve productivity of the citizens by minimizing travel time. Streets will be designed for 'All' and should accommodate pedestrians, hawkers, cyclists, public transport and private vehicles. Vehicular movement will come down significantly and, in the process, improve the air quality and make the city 'breathe'.

Waste Water Treatment & Reuse: Green cities would facilitate 100% onsite waste water treatment and its reuse. Onsite treatment of waste water should be encouraged, and the treated water can be used for non-potable purposes, thereby reducing dependence on potable water. Use of dedicated Purple lines to convey treated water will become a reality. Biological process of treating waste through Phytoremediation should be adopted across the cities.

Open Spaces & Green Cover: Green cities should dedicate 10 % of city area for open spaces and should be designed for 33% Green Cover, which does not call for significant investment and mitigates urban heat island effect. It should provide world-class recreation facilities and biodiversity parks. Today, Singapore has demonstrated that 46 % of green spaces can be achieved. India has all the potential to surpass the feat of Singapore and set new global benchmarks. This gives us an opportunity to develop and incorporate out-of-the box models.

Stakeholder Participation: In order to facilitate, Green cities, private sector will have to play a key role. The key to implement green city projects is to develop a clear business model. Public-private-community partnerships (PPCP) should also be forged to ensure success of the project.

India is among one of the first few countries to develop an exclusive rating system for Green Cities. IGBC Green Cities Rating, standards for greening of such large developments, based on sound environmental principles has been launched in 2015. IGBC is working closely with development authorities and developers to apply green concepts and planning principles in several Indian Cities, resulting in reduced environmental impacts that are measurable and thus improving the overall quality of life.

SMART CITIES ARE ALSO GREEN CITIES

In June 2014, the Government of India announced its ambitious plan to build smart cities across the country with focus on building new smart cities and redeveloping existing urban regions with populations of over 1,00,000 people. In the approach of the Smart Cities Mission of Government of India, the objective is to promote cities that provide core infrastructure and give a decent quality of life to its citizens, a clean and sustainable environment and application of 'Smart' Solutions. The focus is on sustainable and inclusive development.

Hon'ble Prime Minister's initiative of developing 100 Smart Cities will soon be a game changer and usher in a paradigm shift in the way cities are conceived and designed. Green cities and smart cities go together, and the former is an integral part of the latter. IGBC is partnering with the Government in taking forward the Smart Cities Mission.

Core infrastructure elements in a Smart City are:

- Adequate water supply
- Assured electricity supply
- Sanitation
- Solid waste management
- Efficient urban mobility and public transport
- Affordable housing
- Robust IT connectivity
- e-Governance
- Citizen participation
- Sustainable environment
- Safety and security of citizens
- Health and education.

These existing cities have a wonderful opportunity to optimize the resources, create a robust infrastructure and enhanced quality of life for citizens. Against this background, Indian Green Building Council (IGBC) has developed IGBC Green Cities (Existing cities) Rating System.

Focus Areas of IGBC Green Cities (Existing Cities) Rating System include the following:

- Ecology & Preservation
- Citizen Welfare
- Land Use
- City Transportation
- Infrastructure Efficiency
- Innovation in City.

The key benefits of cities going the green way include the following:

❖ Air Quality Improvement (PM2.5, PM10, CO_2, NOx, SOx)

❖ Increased Urban Green Cover (At least 9 sq.m. per capita meeting WHO Standard)

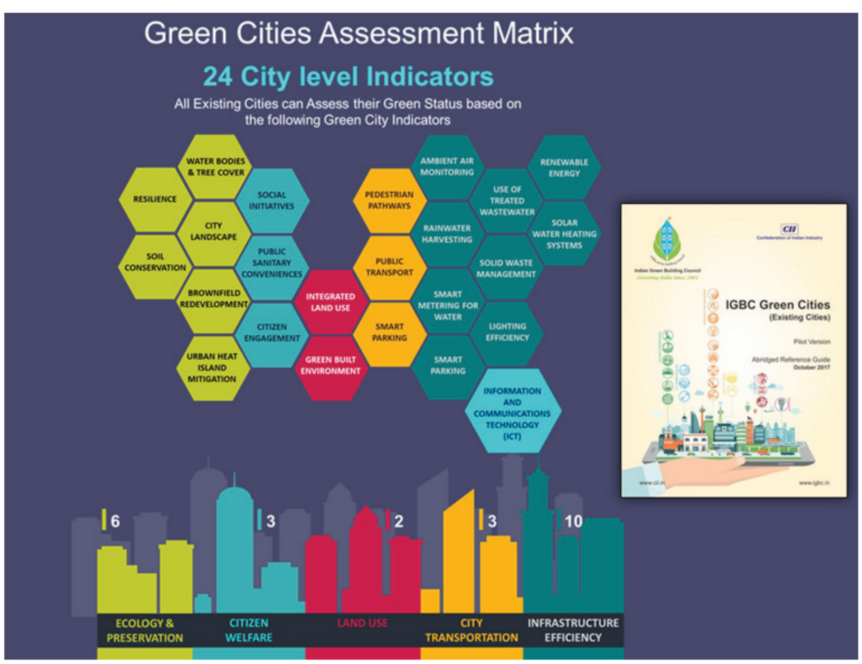
❖ Reduced Energy Demand by 20-30% (2 – 2.5 MW per million sq.ft. of Green Buildings)

❖ Enhanced Water Efficiency by 30-40% (45 litres to 30 litres per person per day in Commercial, 135 litres to 100 litres per person per day in Residential)

❖ Waste Segregation & Recycling (Develop Recycling industry)

❖ e-Governance (Ease of Transactions)

❖ Citizen Participation.



IGBC GREEN CITIES RATING SYSTEM ARE ALIGNED WITH SDGS

Green buildings and green cities contribute significantly towards meeting the Sustainable Development Goals (SDGs). The adjoining infographic illustrates the role of green buildings in meeting SDGs.

Greening of cities will mean significant progress in decoupling economic growth from climate change, poverty and inequality, helping to achieve the goals and creating a greener world that we can all be proud to call home.

GREEN & SMART CITIES ACROSS THE COUNTRY

Existing Cities which have adopted IGBC Green Cities Rating System for city level performance mapping under 24 green city indicators are:

- Kedarnath, Uttarakhand (IGBC Platinum rated city)
- Rajkot ABD, Gujarat (IGBC Platinum rated city)
- Bhopal, Madhya Pradesh
- Panchkula, Haryana
- Visakhapatnam, Andhra Pradesh.

Greenfield Cities which have adopted IGBC Green Cities Rating System for green masterplan & design are:

- Dholera, Gujarat (IGBC Platinum rated city)
- New Town Kolkata, West Bengal (IGBC Platinum rated city)
- Sri City, Andhra Pradesh (IGBC Gold rated city)
- Mahindra Industrial City Chennai, Tamil Nadu (IGBC Gold rated city)
- Mahindra Industrial City Ahmedabad, Gujarat (IGBC Platinum rated city)
- Gujarat International Finance Tec-City, Gujarat
- Aurangabad Industrial City, Maharashtra
- Model Economic Township, Haryana.

Covering an approximate large development of 5,77,150 Hectares in greenfield & existing cities and 45+ townships.

RAJKOT SMART CITY, GUJARAT

Rajkot Smart City has been awarded the IGBC Green Cities 'Platinum' rating for the green initiatives taken up for design and implementation. Rajkot Smart City is the first smart city in India to achieve the IGBC Green Cities Rating.

The Indian Green Building Council recognises several initiatives taken which include enhancing the city's resilience to earth quakes, cyclones, drought & flood, energy efficiency water management, waste management, 100% LED lamps for street lighting, extensive utilization of

rooftop solar PVs, treatment of 100% wastewater generated from the city and waste recycling.

Some of the Green City features of Rajkot Smart City include the following:

- **Green Cover:** Green cover improved by 25% with tree preservation & plantation initiatives as per Gujarat DCR
- **Resilience:** Comprehensive Hazard and Risk Analysis based on Zonation maps, (Earthquake, Cyclone, Drought & Flood) with prevention and mitigation measures integrated in master planning.
- **Water Bodies:** Two natural lakes and reservoirs has been reinforced with

rejuvenation of 4 lakes covering 4 km catchment areas, resulting in improvement in water table

- **Housing for all:** 23,489 dwelling units developed under various schemes and action plan developed towards Slum-free City for 135 slums, 15% dwelling units for affordable category housing (EWS/LIG) proposed in ABD area
- **Health & Hygiene:** 21 public toilet complexes in the ABD area will add to the 137 Public Toilets of Rajkot City contributing to 15% increase in no. of Public toilets in the city
- **Integrated Land use:** ABD developed as new CBD for Rajkot city, FSI of 4 along BRT corridor (Transit Oriented Development initiative)
- **Walkability:** 100% of 23 km road network in ABD planned with footpaths on both sides, cycle lane & parking stations are proposed
- **Parking:** Multi-Level car parking (MLCP) with 780 car parking and 550 two-wheeler capacity proposed in the city with smart parking management initiatives
- **Water management :** 100% water supply coverage, 100% consumer metering, 24x7 supply through concept of District Metered Areas, 70% treatment of wastewater in Rajkot city and 95% reuse of treated water, 100% treatment & reuse planned in ABD
- **Energy Management :** 100% LED lighting, 3.2 MWp solar power generation proposed
- **Waste Management :** 100% door to door collection, 100% Municipal and C&D waste treated, City has planned 5 TPD Waste to compost plant in each ward. 1000 TPD Waste to Energy plant at landfill site
- **Air Quality :** 20 Air quality monitoring stations across Rajkot City including ABD area
- **Smart City Command & Control:** Rajkot ICCC operational since Feb 2018 with expanded scope of Rajkot Police under Safe and Secured Gujarat Initiative
- **Citizen Engagement:** Involvement of 9 Lac people in the process of Smart City initiatives (70% of population).

NEW TOWN KOLKATA, WEST BENGAL

New Town Kolkata, located in the north-eastern fringes of Kolkata, North 24 Paraganas district, is a planned greenfield satellite city with 3075 Ha planned development. New Town is planned with a Futuristic Design with world class urban infrastructure and is a 'solar' city with IGBC 'Platinum' Rating.

New Town is India's 1st green-rated satellite city and is a unique blend of ancient architectural practices and modern technological innovations. The city has already started becoming a much sought-after city for many national and international companies who wish to enhance the quality of life of its employees and explore new growth opportunities.

Compact City Development: The city is planned to achieve 49% of Residential Land use in CBD area and 40% Mixed Use Development (Walk-to-Work Concept). The City has planned strategies to achieve the Land Use Planning objectives of creating a Compact City with mixed land use, meeting the Housing demand and developing a business hub having access to education & healthcare.

Health and Well Being: 30% of land use area has been dedicated for green & open spaces which include city green cover and water bodies to ensure adequate spaces for public recreation. All open spaces are within 400 m walking distance from all residential neighbourhoods & offices.

Sustainable Mobility: The City has planned strategies to achieve the Sustainable Mobility objectives of reducing dependence on private vehicles, barrier free, walkable city with efficient last mile connectivity options for Public Transport managed through Intelligent traffic & parking management system.

Energy Efficiency: New Town Kolkata aspires to be a Solar City by taking conscious steps towards energy efficiency reducing the energy demand and then meeting at least 10% of the city's energy requirement through solar energy. Key initiatives planned under the Solar City proposal include Solar Powered Water Pumps, Roof top semi-transparent solar panels with net metering system, Solar lights for parks, Bus terminuses and traffic signals all government offices with LED lighting. As a "Solar City", the city ensures at least 5% of energy use at government buildings is through Renewable Energy.

Solid Waste Management: The vision is to have a clean and litter free city by having a mandate on solid waste segregation. Based on the composition of waste generated, guidelines have been developed for recycling of each type of waste, thereby reducing waste going to the landfill site.

Water Efficiency: The City has planned strategies to achieve the Water Efficiency objectives of preserving existing water resources, effective storm water management, water recycling & reuse, maintaining surface & groundwater quality to sustain city ecosystem and health of citizens.

Information and Communications Technology (ICT) Integration: The City has planned strategies to achieve the ICT objectives of creating a smart and safe city having ICT enabled Government services and AI & drone-based monitoring system.

BHOPAL SMART CITY, MADHYA PRADESH

Government of India plans to implement Smart City Program for next 5 years (FY 2015-16 to FY 2019-20) to transform 100 Indian Cities

to Smart Cities. The objective is to promote cities that provide core infrastructure and give a decent quality of life to its citizens, a clean and sustainable environment and apply `smart solutions'. The focus is on sustainable and inclusive development and the idea is to look at compact areas, create a replicable model which will act like a light house to other aspiring cities. For this, GoI floated a Smart Cities Challenge, a competition designed to inspire and support municipal leaders as they develop smart proposals to improve residents' lives. In 2015, in first round of competition, Bhopal was one of the 20 cities selected, which would receive funding from the Ministry of Urban Development. Government of Madhya Pradesh has incorporated a special purpose vehicle (SPV) – Bhopal Smart City Development Corporation Limited (BSCDCL) to plan, design, implement, coordinate and monitor the smart city projects in Bhopal. BSCDCL is a company incorporated under Indian Companies Act 2013 with equal shareholding from Madhya Pradesh Urban Development Company Limited (MPUDCL) on behalf of Government of Madhya Pradesh (GoMP) and Bhopal Municipal Corporation (BMC). BSCDCL has received funds from GoI and GoMP for the development of smart city in Bhopal.

Under Area Based Development (ABD) initiative, Bhopal's proposal includes redevelopment of 342 acre of North & South TT Nagar, which is also the only redevelopment and rehabilitation project among the 100 smart cities selected by GoI. As per SCP, the area based development would be a state of art smart city in the heart of the city of Bhopal with all modern features in a sustainable manner and would generate more job opportunities. The area based development would be as state of art smart city in the heart of the city of Bhopal with all modern features in most climate resilient manner and would generate more job opportunities. The ABD area is being developed as High Density Mixed-Use Development along the three transit zones. The layout of the project area has been designed on the principles of Transit Oriented Development (TOD). The pedestrian entry at the frontage and vehicular access from the back side of the plot is another element achieved in the design. Currently the ABD area is predominantly occupied by govt. houses, which need to be

relocated to vacate the land. 3100 units are planned to be constructed for this purpose. These units have increased carpet area and new design. Apart from this there are 11 schools and approx. 200 small and medium commercial establishments and around 50 religious establishments which will be strategically relocated. The schools will be facilitated with modern facilities and more play and open areas. The Smart City project is registered under IGBC Green Cities Rating and under green certification process.

Transit Oriented Development

The ABD area is being developed as High Density Mixed-Use Development along the three transit zones. The layout of the project area has been designed on the principles of Transit Oriented Development (TOD). To achieve higher density various changes in FAR and building heights have been proposed. Residential and commercial population of 60,000 and 56,000 resp. is estimated which gives a high density of around 864 pph (people per hectare) for the ABD area. Connecting parks and gardens; pedestrian centricity and cycle tracks are the foremost features of the master plan. The pedestrian entry at the frontage and vehicular access from the back side of the plot is another element achieved in the design.

State of art Infrastructure Services

The ABD area will be facilitated with state of art infrastructure services. These infrastructures will include 24x7 water supply and power, underground utility corridor, ICT infrastructure, smart street lighting, automated solid waste system, to name a few. 80 % of the buildings in the area will be green rated. An integrated command and control centre will monitor and manage the ABD area as well as entire city. Waste Generated shall be treated by Treatment Plants. Latest technology is used for setting up these Sewerage treatment plant. The treated water is used for flushing, gardening, road washing, Landscape & irrigation of plants & shrubs.

Green Infrastructure Initiatives include:

- Street Scape: All the roads are proposed with tree trenches to maintain the Green of the area. The open spaces are designed with a strategy of landscape and buildings merging into each other. It also consists of meandering pathways that are shaded by the use of native trees on their sides.
- Dedicated footpaths & cycle tracks provide the pedestrians and cyclists carefree way to move around in the ABD area.
- Utility Corridor helps in reducing the need for rework and repairs works, thus providing hassle free movement to vehicles.
- Command Centre: A common command centre is placed in ABD area which controls all the utilities and the data for the same shall be recorded. A careful monitoring can be done in this way for providing a safer community to people.
- Traffic Management Plan: Traffic management study and the dedicated routing helps carefree movement of vehicles.

Environmental Guidelines for ABD Project Area include:

- Green Building Guidelines: A MoU has already been signed with Indian Green Building Council (IGBC) and BSCDCL for ratings in ABD Project. All new construction within the ABD Project area shall have Green Building Certification.
- Rain Water Harvesting: All newly constructed building shall have rain water harvesting and rain water recharge facility.
- Zero Water Discharge: The treated water from the Sewerage Treatment Plant shall be used for irrigation, road & car washing. Each individual plot shall be having its own STP and the recycled water shall be used which in turn reduce the load on fresh water.
- Energy Conservation and Usage from Renewable Sources: All the conditions pertaining to Energy Conservation shall be adhered to as per clauses in the environmental clearance letter issued for ABD area. As per

Smart City Guidelines a minimum of 10% energy shall be consumed from Renewable Sources, like solar panels.

- Guidelines for Differently Abled and Physically Challenged: All the buildings in ABD Area shall be accessible for differently abled and physically challenged persons. Provisions other than the accessibility shall be made in all buildings, facilities and external spaces used by public in accordance with the provisions of the National Building Code of India 2016, and as per Applicable Laws, as updated from time to time.

TALE OF TWO CITIES - EFFORTS FOR INCLUSIVE CITIES

With the demographic explosion from 100 crores in 2000 to nearly 135 crores plus, India is likely to cross the 1.4 billion population shortly. We are literally adding with 2 crores population each year and more than fifty percent of it going into urban areas. India no more "lives in the villages" as Gandhiji had observed at the time of independence with 16 % urban and 84 % rural population. Over the 73 years the rural-urban shift has been gradual and pace increasing. India would have 40 % living in urban areas with over 7300 urban centres of 7 mega cities [50 Lakhs plus], 60 metro cities [10 lakhs plus], 170 municipal corporation cities[around 5 lakhs plus], 500 AMRUT cities [1 Lakh plus cities] and balance cities and towns of various population. Cities are engines of growth and contribute to 65% of GDP and likely to be 70% shortly. India's urban population is likely to be around 57 crores by 2030 and 87 crores by 2050.

It is absolutely essential that cities get geared up with the right level of infrastructure and facilities to deal with the growing population and all round growth potential. While some initiatives were taken under JNNURM for 63 cities in the 2004-2014 period ,a major thrust for urban rejuvenation and transformation was ushered in during present government policies and programmes from 2014 onwards through development of 100 Smart cities, 500 AMRUT cities , Housing for All under PMAY, Swachh Bharat Mission for Sanitation for All and Waste Management initiatives and National Urban Livelihood Mission for Poverty Alleviation and Urban Employment generation for the urban poor, low income groups, marginalised and disadvantaged sections of community.

While the above are revolutionary interventions, it takes time for deep dive impact between policies, programmes and project implementation.

Some critical areas are the deep divide between haves and have nots. While cities have symbols of heights of prosperity in all walks of life, it also has depths of poverty impact for the bottom half. The socio economic divide cover High Income group[5%], Middle income group [25%],Low income group [30%] and Economically Weaker Sections [around 40%] which will also include the BPL families.

If cities are to develop as "Inclusive Cities", it is imperative that benefits of development for all basic needs are also made available to all groups through policy interventions and deployment of all resources like access to education, employment, land, basic services, materials and finances.

The Smart Cities and AMRUT cities have good opportunities to strive for creating inclusive cities through the urban reforms and transformation agenda. Some of the details are briefly highlighted below:

Livelihood Support and Employment Generation

- Government of India launched National Urban Livelihood Mission (NULM) - a flagship programme, to address the vulnerabilities of the urban poor.
- While residential vulnerability is addressed by PMAY(U), and social vulnerabilities by other social sector schemes for the socially disadvantaged sections of the society (special programmes for SC/ST/women/PWDs etc), NULM addresses the economic / occupational vulnerabilities.
- The approach is to encourage the urban poor

to form and strengthen their own grass root level institutions. The emphasis is on Women. Formation of SHGs and their federations at ward/slum level and city level are part of this strategy.

- The approach involves enabling them through appropriate Skilling of the urban poor to undertake/ join self-employment or salaries employment; encourage and promote their self-employment initiatives through enabling financial literacy and access to bank loans, either individually or as groups for undertaking remunerative activities.
- As of now, over 5 million women have formed into over 4.8 lakh Self Help Groups (SHG) in urban areas.
- The basic conviction of NULM is that the urban poor are inherently willing to improve their livelihood and given appropriate handholding through skill and access to employment/financial facilitation, it would enable them to achieve their ambition in life. Of the total 4.8 lakh SHGs over 60% are undertaking livelihood activities of various kinds.
- For the loan they avail from Banks (up to Rs 2 lakh for an individual member or about Rs 10 lakh for a group these members), NULM provides interest subvention. They need to pay only 7 per cent as interest and the balance is given by the government for those giving regular repayment. Of this as well, the women groups which pay regularly get an additional 3 % interest subvention.
- NULM also promotes shelters for the urban homeless and support for Street vendors who are an important component of the urban economy. For the street vendors, in line with the Street vendors (Protection of Livelihoods and regulation of street vending) Act 2014, the mission supports formulation of street vending plans in towns, development of Vending Zones and also street vending infrastructure.
- These efforts have contributed to bring down the urban poverty level. Sure is that over 25 million urban poor have been encouraged, shown the way and over 60% have gone into livelihood mode.

Housing

Under the Housing for All agenda under Pradhan Mantra Awas Yojana [PMAY-Urban] over 12 million families have benefited for appropriate housing solutions under 4 vertical delivery options to families who are houseless and landless. This will cover major slum improvement and affordable and acceptable housing solutions with incremental approach. These include access to land and basic services , affordable housing loans with interest subvention up to 6.5% and access to cost effective / disaster resistant and environment friendly building materials and technologies . The urban local bodies and housing agencies are working closely to identify affordable land parcels for families who are landless and houseless.

Sanitation Facilities

This is a major segment where Swachh Bharat Mission has helped to provide sanitation facilities through toilets and disposal systems for individual use and public facilities for common use. The cities have all become open defecation free [ODF].

Education and Vocational Skill development

The Skill Development Ministry [NSDC] and Housing and Urban Affairs ministry has worked in close collaboration. Further the New Education Policy also facilitates the smooth transition from school level education to professional vocational education and Skill development options through network of training institutions/skill development centres for various vocations and job needs.

These efforts have helped to narrow the gap between affluent and poorer families.

This will help remove gross inequities among all citizens and also remove social tensions and improve health aspects with access to housing, water supply, sanitation and energy supply. The access to education and health facilities expansion for post covid situation needs will also help improve the nutritional and health needs of the poorer sections of the cities. The impact for these initiatives can be seen in the ensuing years.

IGBC GREEN RATING SYSTEMS FOR BUILDINGS AND BUILT ENVIRONMENT

IGBC believes that each building type needs a different kind of design approach. In this regard, IGBC has launched 28 green rating systems to address various building typologies and built environment

All IGBC Rating System have been developed based on the holistic approach of Panchabhutas and are a perfect blend of ancient architectural practices and modern technological innovations. IGBC rating systems are evolved so as to be comprehensive and at the same time user-friendly.

Various types of building typologies in a green city like- individual homes, schools, hospitals, new buildings, existing buildings, places of workshop and other forms of built environment can adopt IGBC green building rating systems and in the process facilitate in building a greener and healthier India.

MARKET POTENTIAL FOR GREEN BUILDING PRODUCTS AND TECHNOLOGIES

In terms of market potential for green products, materials and technologies, it is estimated that by the year 2025, it will be about USD 300 billion. This offers excellent growth opportunities for the manufacturers of green products, materials and technologies.

Today, Indian industry has taken up activities and initiatives to ensure that growth is not at the cost of environment and has clearly realized that pursuing ecological sustainability ultimately results in making Indian industry more competitive. IGBC would continue to work more closely with the stakeholders in building a greener and healthier India.

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Transportation Systems in the Future

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INTRODUCTION

The Engineering for the Future is linked to the development visions and imaginations for the future, which is to be engineered as has been done in the past centuries across the world. There are many kinds of engineers – some deal with microscopic systems while others build skyscrapers, and even others have built the cars, planes, mobile phones, laptops and so on to make life comfortable. There will be continued demand for new technology, products and materials and Engineers have skills to develop products which could be imagined. The humanity will have more demands on engineers in future for innovations with new opportunities. Engineering combines mathematics and science theories to practical problems, which have created profound effects on the way we live in cities, the way we travel, technology we use for accessing information or even the way we get our health problems solved. And that is not all; all manufactured products we use in our lifestyle are only through engineering designs. It is, therefore, not a surprise that almost all Fortune 500 CEOs have a common base like engineering undergraduate degrees.

The 'Transportation Systems', as the theme of this paper appears to be linked to the works of civil engineers. However, the transportation systems' that are present now and those likely to be in use in coming decades are not going to be the contributions of the civil engineers alone, but many other engineering disciplines. To design and execute infrastructure requirements of transportation systems the civil engineering skills were used, which was distinguished from military engineering as the engineers were engaged in peaceful activities. It had the foundation in France in 1716 with the Bridge and Highway Corps, out of which grew the École Nationale des Ponts et Chaussées (National School of Bridges and Highways) in 1747. The École Polytechnique was founded in Paris in 1794 and a group of young men in 1818 founded the Institution of Civil Engineers in Great Britain. As the formal education in engineering sciences became widely available and as other countries followed the lead of France and Germany, University College, London, was founded in 1826.Rensselaer Polytechnic Institute, founded in 1824, offered the first courses in civil engineering in the United States. In India, Thomason College was established in Roorkee in 1847, which was the first engineering college in entire British Empire, and was later renamed as Thomason College of Civil Engineering in 1854.

Future of Engineering

Engineers or the engineering ideas only have driven the civilization to grow for the way we live and work in safe, efficient and sustainable environments. All the infrastructure systems for water, gas, electricity and telecommunications or even for a new system of transportation with an innovative technology to be implemented, involves engineering skills and innovations. The 21stcentury is going to see a host of never before innovations in the fields of energy, medicine, transportation, robotics, and artificial intelligence, and engineers will invent that future, and therefore, a new breed of engineers is required for whom lifelong learning/education and just-in-time knowledge is essential. The half-life of engineering knowledge is three to five years, and therefore, as the Dean at Stanford University, Professor Plummer used to tell students 'it doesn't matter what we teach you because it will be obsolete when you graduate……'. Further, the students of engineering courses also to be taught that failure is acceptable in real world, and it is an important life skill 'how to recover from failure'. Therefore, the new breed will have to be educated and not to be trained only, so as to build life, be entrepreneurial, and be with all other needed skills for engineering innovations for the future. Thus, the creativity, innovation, project-based learning, and by working in teams modern engineers will shape the future of engineering to provide the products demanded by the humanity.

Revolution in Transportation

Since early times of civilization human beings have been trying to find ways to make traveling faster and more convenient; first with invention of wheel, then carts and wagons, steam power, and the internal combustion engine. The objective to move passengers and freight faster, in larger quantities, safely and efficiently remained the core motivation to improve transport technology over last two centuries. With this backdrop, growth in road/rail /water/air transportation and associated infrastructure has been unprecedented in 20th century to achieve higher speed, comfort and economy by access controlled highways/ expressways, high-speed railway, faster and bigger aircrafts and modern maritime vessels in various countries across the world. These have been very energy intensive and polluting; while a vast majority of world population was deprived of such advancements as they could not afford even the luxury to own a motor vehicle. Revolution of the transportation systems continued with electrification (electric vehicles/ locomotives), automation (driver-less cars) and shared ride for mobility (especially in case of urban mobility with the idea of 'mobility as a service').

The human population on earth is fast increasing with steep rate of urbanization globally, as a result of which the traditional transportation systems developed in last one century will not be able to sustain the modern-day demand for mobility, and the congestion and inefficiencies now cost the global economy heavily. In addition, the existing road/rail/water/air transportation systems do not work in seamless integration contributing to further cost and delay. Moreover, with the current reliance on fossil fuels, transportation is a major contributor to greenhouse gas emissions, causing climate change and risk to human health and safety. The mobility revolution through smartphones is already becoming the new normal, and the 800 cars per 1000 people in USA and 600 cars per 1000 people in Europe are going to shrink drastically. The smartphone is becoming the most powerful tool for mobility and the transport revolution is moving forward for zero emissions, zero accidents and zero ownership, and the Big-data, IoT (internet of things) and zero emission technologies provide the hope. The cars will still be there, but the energy that powers them and the way in which they are bought, leased or rented and operated will certainly change in the context of mobility in future.

Three common themes driving the transportation innovations are: smart technology, electrification and automation, and expansion of these technologies will be the major contributors to the developments of transportation systems in the future. Though the idea of a completely autonomous vehicle is exciting, it is extremely scary for the road environment in India and many other less developed countries with poor and non-standard road infrastructure as well as highly mixed traffic and unsafe driving culture of the road traffic. While it is clear that driverless (autonomous) vehicles could change the entire economics of passenger transport with massive benefits, there is just a lot of hype right now, and it is going to take a long time before becoming a reality in India.

Successful demonstration flights of autonomous aerial vehicles (AAVs), which are essentially autonomous human-carrying drones, have established that public transportation can take to the skies to avoid the congestions on urban roads. Similarly, 5G-connected urban air mobility, controlled through a smart city command center, is set to be the world's first Air Taxi to debut in Qatar for the FIFA World Cup in 2022. Hoverbike is another aerial mode using VTOL platform, which resembles a common motorbike, where a human operator/traveller rides and controls the vehicle.

The idea of the Hyperloop (a guided tube concept), often called the fifth mode, was first envisioned by Elon Musk in 2012 as a future mode of travel. The principle is based on the movement of people in capsules or pods using magnetic levitation technology for propulsion that travel at high speed (capable of 1000 to 1500 km/h) through tubes with low pressure environment void of air, for travel over long distances (e.g. between cities, countries or continents). A 500 meter test track of hyperloop is existing in Virginia, USA and many countries including India are actively considering it.

Outline of the Chapter

The major objective of writing this paper (or chapter) is to present the information to the readers on past, present and future of transport system broadly in the Indian context but not devoid of an international canvas. Moreover, it deals largely with passenger transport modes of travel though some contextual details are included for goods transportation. A brief account of how the transportation systems have evolved over the last century and as it is now is given in section 1.2. The present status of transport in India and its role in inclusive growth in the country is presented in section 1.3. The next section 1.4 discusses the passenger and freight transportation system that is likely to take shape in the future. Urban transport, which assumes a great significance in providing the intra-city mobility, is covered in section 1.5. It includes, motorised and non-motorised traffic, electric vehicles and, conventional and innovative public transport systems. The sustainability issues of the various systems discussed in above two sections are covered in section 1.6 and the important conclusions and directions for the policy makers and transport providers are discussed in section 1.7.

History of Transport System

A dictionary definition for transportation is 'a means of conveyance or travel from one place to another' for the movement of goods and persons. In human history, initially the only form of transport apart from walking was by using domestic animals like horses, oxen and donkeys, dogs, camels, etc. The civilisations, therefore, were also found to have developed on the banks of the rivers and other waterfronts for advantage of water transport and they used boat-like canoe made of dugout tree trunk. Means of transport started with rudimentary slides with tree trunk or animal skin, and from there it grew based on inventions or simple understanding of motive powers, which started with the domestic animals and later using invention of machine power.

The Global Scenario

One of the most important inventions for transport has been the wheel in 3500 B.C. in Mesopotamian civilisation (the present Iraq) with cut out piece of a tree trunk, basically for making pottery, which later with associated axle made the carts or wheel burrows. Animal drawn wheeled vehicles were developed in Europe and India in the 4th millennium B.C. and later in China about 1700 B.C.

With the invention of wheel after fire, life changed tremendously for mankind. Human being could move faster and farther, as a result of which could see more, conquer more and also exploit more resources. This probably shaped the destiny of surface transport as we see today, and it needed the infrastructure in the form of track for efficient movement. Later since 2000 B.C. a type of wheel with hub connecting to the rim by spokes was in existence, and thus for almost 5000 years, the carts (or wagons or carriages) drawn by oxen or horses were the means of transportation for people and goods. Thus, developments in transportation systems are synonymous to the objective of transporting large quantities of goods or numbers of people over long distances at high speeds in comfort and safety, which has also been an index of civilization and in particular of technological progress.

Existing means of transport were continuously being improved upon from the beginning of the civilisation and types of transportation in existence are shown in the **Fig. 1**.

The modern transportation systems have grown continuously and unabated with ability and need of transporting large volume of goods and number of people over long distances with comfort and safety and at high speed. Technological advances have also provided tremendous flexibilities and choices to the users of transportation systems.

A brief history of various forms of transportation is given here.

Road Transport

With the invention of wheel, there was a need of a treated surface for convenient movement of the wheel. The idea of developing formal road network started only in Roman Empire, especially for military, political and commercial reasons, and primarily for growing the empire. It begun in the fourth century B.C. and at maximum expansion of Roman Empire it had 100,000 kilometres of road connecting Rome to various parts of the empire.

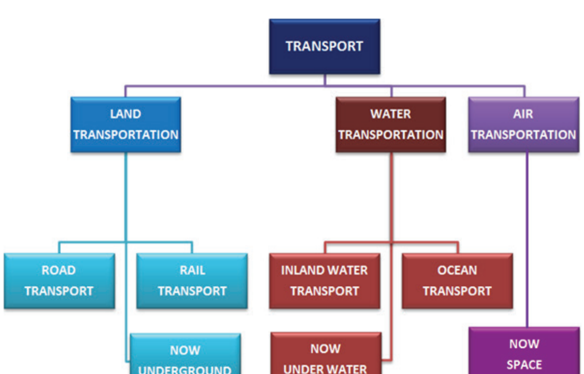

Fig. 1 : Modes of transport

Motor vehicles based on internal combustion engine were first developed in France in 1860, and thereafter, there were several other developments in the Europe and USA. However, the first successful modern automobile was introduced and launched by Henry Ford as the Model T Ford in 1903 and mass production started in 1908. Later in subsequent decades of twentieth century the big-three of Ford, Chrysler and General Motors have put the entire America and many other parts of the world on wheels.

The history of trucks, like that of cars, started in 1876 with the invention of the four-stroke internal combustion engine. Since then, technology has made great strides and modern trucks are equipped with clean engines, and provide a great active and passive safety, but remained driven by engines that use fossil fuels, responsible for large CO2 emissions and other harmful gases that pollute the environment.

Especially in the last 30 years the automotive industry has made enormous progress in the reduction of pollution by making it possible to use cleaner fuels. Today, the automobile industries of the world produce more than 70 million vehicles every year, and a steep increase in price of crude oil has led to not only the developments for alternative fuels but also various green cars such as hybrid cars, battery operated cars, hydrogen cars, and cars running on other alternative fuels.

Rail Transport

The first revolution in mass transport systems using track based train of vehicles came around 1780, when James Watt, the Scottish inventor built the first steam engine in 1769. Later, the steam locomotive was built by George Stephenson in 1829 as formal railway to move the wagons on rails. The steam engine was mostly fuelled by coal, wood or oil, whereas today's trains are powered by electricity or diesel.

Iron rails were laid first time in 1767 at coal mines and later in 1825 the first passenger railway was started between Stockton to Darlington (27 miles) in UK, built by Stephenson. While early railway used horses, later steam engines and the locomotives were used to pull the trains. The underground railway (tube railway) was first built in 1863 in London. The electric trains and the trams were developed in 1880. High speed rail system development was in focus throughout the last two centuries, and could achieve a speed of about 300 kmph in Western Europe and Japan as well as in a few other countries. The fastest commercial High Speed Rail system, which uses magnetic levitation technology, can go up to 574 km/hr (TGV in France).

Water Transport

Most ancient civilisations started along the river banks and used water transport mostly for transporting goods. Greeks and Romans used the waterways extensively for commerce and military purposes, while Egyptians were the first to use the seagoing vessels even in 1500 B.C. for their trade. In Asia, Chinese were using the internal waterways as early as 4th century B.C. Beginning from the canoe made from tree trunks, today's water transport is highly advanced and serving the mankind for continental shipping/ transportation of almost everything. The Spanish Navy launched the first electric, battery-powered submarine in 1888, which happened to be the first modern military submarine. Further, specific military requirements have also developed both surface and under-water transport systems for their effective operations in the form of modern submarines and other amphibian vehicles.

Air Transport

The first man-made object to fly in the aerial space was the balloon, and later the first successful flight of glider was in Germany in 1890s achieved by Otto Lilienthal. Thereafter, the Wright brothers (Wilbur and Orville) in America inspired by success of Lilienthal, made the world's first successful engine-powered and double-winged propeller guided flight carrying man to the sky in 1903. This success was the start of a history of tremendous developments in aviation and later for space flights. The World War I (1914-1918) also provided an accelerated impetus during initial years for the developments of aircraft and associated technologies of aviation industry. Today's commercial aircraft can fly at almost 1000 kmph speed and also carry about 850 people in one flight to provide transportation at lower cost per pass-km of travel and in less time. Also, another group of highly advanced unmanned remote controlled aircrafts are being used in military operations, while use of drones has become very common for civilian activities like aerial photography and other specialised purposes.

The Indian Scenario

The early developments of transportation systems with carts and wagons drawn by domestic animals were common globally with no exception in India. Vedic literature also mentions about the land and water transport only, and refers to use of domesticated animals for transport and later talks of the use of vehicle as 'Yana', i.e. chariots. Harappa and Mahenjodaro civilization also have evidences of using public passenger chariots and of formal roads in 3rd millennium B C Kautilya, the celebrated economist of the Mourayan period has written about the roads of different widths. In the regime of Chandra Gupta Mourya and Emperor Ashoka, the Greek and Chinese travellers have given detailed account of transport systems in India. During Moghul period also the roads and transport were well developed for the growth of trade and commerce and Shershah was very famous for the construction of roads, who in 16th century built the Grant Trunk Road from Calcutta to Peshawar, which was later extended to Kabul and Chittagong port. During British rule in India the road and transport development was for the convenience of marketing and administration. Later Lord Dalhousie created the public works department for the improvement of transport infrastructures, but any meaningful development of transport was seen in the last fifty years of British rule only.

All other modes of transport were also developed in India, and a brief account of each is given here.

Air Transport

Air transport was used first-time in India, when an aircraft carried mail from Allahabad to Naini across the river Ganga in 1911. After World War I, the British Imperial Airways started regular air service to India for the first time in 1924 to provide a link with UK. The first fully manned and managed civil aviation company was set up by TATA sons in 1932. The air transport service in India grew steadily during the pre-nationalisation period between 1932 and 1939, and in post-war (WWII) era there was mushrooming growth of a number of domestic airlines without due consideration of minimum requirements. The interim government formed prior to Independence in September 1946 could not handle the need of this industry and allowed unmanaged growth. Later the indiscriminate licensing of several operators coupled with lack of logistics and maintenance support led to financial losses, sickness, and disintegration of the industry.

Then came the nationalization of the industry by formation of Indian Airlines with the enactment of the Air Corporations Act, 1953 by merger of seven former independent airlines. The Ministry of Civil Aviation, Government of India owned both corporations: Indian Airlines (domestic) and Air India (international), to provide air services as monopoly for four decades. Open sky policy of Government of India in early 1990s broke this monopoly with the introduction of several private airlines. In India, the policy matters are dealt by Civil Aviation Ministry, while the regulatory functions are assigned to DGCA and infrastructure functions to AAI. The air travel in India had steady growth till the end of 20th century as well as first two decades of 21st century. The national carriers with huge assets but with poor operating efficiency had to merge to one called "Air India", and remained as a burden with losses, when several attempts were made for its privatization also.

Today India has 125 airports in regular use including 11 International airports spread over all the states of the country and the government is planning to have 250 airports by 2030. Actually there are 449 airports/airstrips in the country in various stages of development, and of these 314 are considered serviceable. A hundred percent FDI was allowed for modernization of air traffic services in scheduled and regional air transport services to facilitate developments with the growth. The dramatic increase in air traffic for both passengers and cargo in recent years has placed a heavy strain on the country's major airports as passenger traffic stands at 341m and cargo 3.56 million metric tons today.

Water Transport

It is the movement of goods and passengers on water using boats, steamers and ships and it is categorised as (i) Inland water transportation (IWT) and (ii) Shipping (coastal and overseas). The use of boat as a means of transport is one of the oldest means of transport for mankind, and it is a natural means of transport, which is far less expensive, but slow.

India has about 14,000 km of navigable waterways which comprise rivers, canals, backwaters, creeks, etc. It is the cheapest mode of transport for certain kinds of travel both for long and short distances, but faces stiff competition from the railway and road transport systems due to the speed advantages. For development and regulation of inland waterways in the country the Inland Waterways Authority of India was set up in October 1986. Inland water transport based mobility is not much prevalent in India except in a few northern states and Kerala especially for tourism, and in some places just to cross the river in absence of bridge, with very low popularity.

Ocean transport was by sailing in olden days, which changed to bigger and sophisticated vessels with modern internal combustion engine power, and these are considered most suitable for promoting international trade. The advantages of waterways are that they are suitable for carrying bulky goods and heavy articles very conveniently. India is having 7517 kilometres of coastline and there are 13 major and 200 operable minor and intermediate working ports. Nearly 95 per cent of the country's foreign cargo moves by sea.

Land Transport

The land transport or surface transport can be categorised to road and rail transport, which are most prevalent modes of transport in any part of the world. Depending on the configuration of the road infrastructure several kinds of carriages can be used in road transport ranging from a bicycle, motorcycle and cars, bus, and trucks and other vehicles of various sizes. On the other hand, railway moves on dedicated rail tracks and is most suited for mass transport (public transport) and freight transport over longer distances.

(a) Rail Transport

Railway is one of the economical modes of transport for goods and people and suitable for carrying heavy and bulky loads over long distances. In India, it started with a modest beginning in 1853, when first train steamed from Mumbai (BoriBunder) to Thane (in Maharashtra), a distance of 34 kilometres. Thereafter, in Eastern India, the first passenger railway train ran from Howrah (near Kolkata) to Hoogly in 1854 over a 39-kilometre (24 miles) line that was built and operated by EIR. Over the past more than one-and-half century, Indian Railways have helped the accelerated development of industry and agriculture in the country and played a vital role in socio-economic and industrial developments. In 1873 the first tramway, a 3.8 kilometre (2.4 miles) horse-drawn tramway was opened in Calcutta (now Kolkata) between Sealdah and Armenian Ghat Street. In 1897 lighting in passenger coaches was introduced by many railway companies. In 1902 the Jodhpur Railway became the first to introduce electric lights as standard fixtures and in 1920 electric lighting of signals was introduced between Dadar and Currey Road in Bombay.

The first railway budget was presented in 1925 and in the same year India's first electric passenger train was operated between Victoria terminus and Kurla. Independent India had promoted development of railways as it was considered lifeline of entire India. Mainline electrification, fast train services with Shatabdi and Gatiman Express, computerised ticketing, modernisation of signalling, suburban train services and first Metro rail in Calcutta in 1984, have provided the boost to the image of rail transport. The semi-high-speed rail services like Vande Bharat Express and Tejas Express have also been introduced, which can run at speed of 200 km/h, while high-speed rail is also being planned. It is the world's fourth largest railway network after those of the United States, Russia and China. The railways traverse the length and breadth of the country and carry over 30 million passengers and 2.8 million tons of freight daily across 28 states and union territories. It has 67,415 km route, 95,981 km running track and 123,542 km total track length.

(b) Road Transport

The first motor vehicle appeared in India in the year 1898. Since then, the number has grown very slowly and the motor vehicle use in India started only with World War I. During the War a large number of vehicles were brought to the country and after the War these were sold to general public, and then only such vehicles were available for the purpose of transporting men and materials.

Although, road transport was popular and growing in India, the World War II had retarded its growth for some time. But the growth in subsequent years became phenomenal with its increased popularity. Thus, while in 1938-39 India had only 12,397 goods vehicles and 23,645 buses, by 1950-51 the total motor vehicles in India were 310,000. Due to the growing demands and popularity of road transport, even in British India, several important steps were taken for development of road transport system, and the most significant ones are,

- The Jayakar Committee, 1927
- The Motor Vehicles Act, 1939
- The Post-War Policy Committee, 1943.

These developments were further followed by studies of various expert committees set up by the Government of independent India for rail-road coordination, burden of taxation, transport policy, and several other aspects of transport developments in India. Based on the recommendation of Jayakar Committee, the Indian Roads Congress was established in 1934, and a conference of Chief Engineers at Nagpur in 1943 produced the first 20-year road development plan, known as Nagpur Plan (1943-63). Later, there were other 20-year plans for 1961-81, 1981-2001, and 2001-2021. National Highways Authority of India (NHAI) was constituted by an act of Parliament in 1988, but it became operational only in 1995, and the first task assigned was the implementation of National Highway Development Project from 1998 in different phases. During this golden period of road development in India, the Pradhan Mantri Gram SadakYojana (PMGSY) was also launched in 2000 to provide connectivity and development impetus to the villages.

Though passenger transport using buses started in the beginning of 20th century, it expanded only after WW I and more buses were inducted in the vehicle fleet in independent India. During the last two decades of last century, the scooters, motorcycles, mopeds and cars had become highly popular for personal travel, along with increase in buses and trucks as well for commercial uses leading to stiff competition with railways. Over the years the road transport assumed tremendous popularity, and the share of passenger travel by rail was 77 per cent soon after independence (in 1948) and it gradually declined to 20 per cent by 1988. The passenger transport by road has been in both private and public sector in independent India for its legitimate growth. No doubt, this unprecedented development of road transport made the country's road network as the second largest in the world with significant contribution to GDP. But, it had serious concerns of overloading and poor maintenance in addition to serious road safety issues, unabated encroachments and pollution associated with it.

(c) Urban Transport

The urban public transport system in Indian is believed to have started in 1873 in Calcutta with the introduction of tramcars, which were drawn by horses. After a few years, steam locomotives were introduced to draw these tramcars. Petrol-driven buses replaced the tramcars in 1931. This was the time when other cities of India like Madras (now Chennai), Kanpur, Allahabad (now Prayagraj), Patna, Nagpur and Delhi also introduced city bus transportation system. These urban transport services were either organized by independent motor transport corporations or were directly controlled by Municipal Corporations. Bus Rapid Transit System (BRTS) and Metro rails are the new forms of urban public transport systems. Elaborate details of the use of road and track based systems are given in a later section.

PRESENT STATUS OF TRANSPORT & FUTURE DIRECTIONS

Transport sector in India is growing rapidly. This sector includes well developed roads and highways, a wide spread network of railways, fast growing aviation and developing inland water transport. Out of these, roads and railways are dominant means of transport carrying more than 95 percent of total traffic generated in the country. Intercity transport is mainly met by roads (88%), rail (11%) and a limited share of air transport. The major transport policies of Government at recent times are given in **Table 1**.

Railways

Indian Railways are among the largest rail network globally with its network of almost 1.24 lakh km touching every corner of the country. It runs 13452 passenger trains transporting 23 million travellers daily. It also operates 9141 freight trains to move 3 million ton of freight from one place to another on daily basis. On June 10, 2020, the Indian Railways set an international benchmark by running double stack containers in electrified territory between Botad and Palanpur railway stations of Gujarat. Lucknow division of Northern Railway has developed state-of-the art locomotive WAG12B which is capable of hauling 118 loaded wagons at a maximum speed of 100 km/hr. In spite of all these developments and having an extensive network, Indian Railways are faced with serious issues of capacity constraints and poor infrastructure. The share of rail has dropped from 80% in 1950-51 to mere 11 % in 2019-20. Golden quadrilateral route of Indian railways (line

Table 1 : Major transport policies in India

Sector	Policy/Plan	Highlights
Urban transport	National Urban Transport Policy 2014	Enhancing mobility to support economic growth and development
		Reduce environmental impacts
		Enhancing regulatory and enforcement mechanisms
		AMRUT Program for 500 cities announced in 2015
		100 smart cities plan announced in 2015
	National Mission on Sustainable habitat	Submission under India's National Plan on Climate Change
		One of the key components is promotion of urban public transport
Alternate fuels and vehicles	National Policy on Biofuels	5 % blending of ethanol in petrol in 20 states and eight union territories
		Financial incentives
		Waiver on excise duty for bio-ethanol and excise duty concessions for biodiesel
	National Electric Mobility Mission Plan	Investments in R&D, power, and electric vehicle infrastructure
		Savings from the decrease in liquid fossil fuel consumption
		e-rickshaw legalised in Delhi in 2015
		Substantial lowering of vehicular emissions and decrease in carbon dioxide emissions by 1.3-1.5 % in 2020
		Phase-wise strategy for research and development, demand and supply incentives manufacturing and infrastructure upgrade
Intercity passenger transport	High Speed Rail Project	High Speed Rail Corporation of India Limited (HSRC) formed for development and implementation of high-speed rail projects
		2000 km high-speed railways network (HSR) by 2020
		14 corridors identified
	Air Transport	Air Transport Corporation Act-1953
		Airport Authority of India – 1972
		Open sky policy – 1994
		Air cargo policy – 2019
Efficiency	Fuel Economy Standards for cars	Binding fuel economy standards starting 2017
		Fuel efficiency improvement in cars by 10 % in 2017 , 20 % in 2022
		Automotive Mission Plan (AMP2026)
	Auto Fuel Policy	30 new cities are planned to move to BS IV by 2015
		BS VI in the entire country rolled out in 2020
Freight	Dedicated freight corridors	Double employment potential in 5 years (14.87 % CAGR)
		Triple industrial output in 5 years (24.57 % CAGR)
		Quadruple exports from the region in 5 years (31.95 % CAGR)

connecting Delhi, Mumbai, Chennai and Kolkata) and its two diagonals, for example, constitute just 15 % of the total rail network, but carry about 52 % of passenger traffic and 58 % of freight. The total average speed of Indian Railways in 2017-18 was reported as 23.1 km/hr for good trains and 44.4 km/hr for passenger trains.

In an attempt to introduce a new train travel experience for passengers who are used to travelling by aircraft and air conditioned buses, the Indian Railways has decided to allow private companies to run the trains on selected routes. The first set of 12 trains owned by private firms would be introduced in the year 2023. This would be followed by 45 more such trains in the next fiscal year (i.e., 2023-2024), 50 in 2025-2026, and 44 in 2026-2027. On private trains, only the driver and guard would be railway employees and all other staff would be of the private company which operates the train. The companies will be free to procure train and locomotives from any source of its choice. At present, the IRCTC owned 'Tejas Express' trains, operating in the New Delhi – Lucknow and Mumbai – Ahmedabad sectors are the only trains in the country run by a non-railway operator. Indian Railways is also planning a diamond quadrilateral connecting four major metropolitan cities with high-speed rail system.

Air Transport

The civil aviation industry is vulnerable to several intrinsic and extraneous risks. These include economic boom and bust cycles, volatility in oil price and exchange rates, natural disasters, epidemics, infrastructure challenges, protectionism, wars and political upheavals. The Indian civil aviation industry has managed to exhibit significant resilience against these risks over the last two decades. Air transport in the country is growing steadily with domestic volume of 122 million passengers in 2014-15 to 341 million passengers in 2019-20, registering a compound annual growth rate (CAGR) of more than 11 percent. However, a large section of country's air transport potential remains untapped, even though the Mumbai-Delhi air corridor was ranked the world's tenth busiest route. Air transport accounts 3-4 percent of intercity travel and cover only limited number of cities, and 80% of flight capacity serves only six top metros. The operations of the major airports in India have been privatised and this has resulted in better equipped and cleaner airports with the terminals refurbished and/or expanded. The government is currently planning for another 200 airports over the next 20 years for 'low-cost' air services.

Coastal Shipping & IWT

Ports sector in India is mainly driven by high growth in external trade and this sector has very negligible share in the domestic movement of passengers or freight. 96% of the foreign trade by quantity and 70% by value take place through the ports. There are 12 major ports in India, and another 187 minor and intermediate ports, 43 of which can handle cargo. Maritime transportation in India is managed by the Shipping Corporation of India, a government-owned company that also manages offshore and other marine transport infrastructure in the country. The major ports are operated by central government under Major Port Trusts Act, 1963 and the minor ports are regulated by the respective state governments.

India has an extensive network of navigable inland waterways in the form of rivers, canals, backwaters and creeks with total length of 14,500 kilometres. The total cargo moved by inland waterways is just 0.15% of the total inland traffic in India, as this is confined to a few waterways in Goa, West Bengal, Assam and Kerala. The Inland Waterways Authority of India (IWAI) is the statutory authority in charge of the waterways in India. The inauguration of the multi-modal terminal on river Ganga at Varanasi in 2018 and the commencement of integrated movement of cargo from Kahalgaon in Bihar to Pandu in Assam over three waterways – Ganga, Brahmaputra and the Indo Bangladesh Protocol route, have firmly established that the inland water transport can be a cheaper and more environmental friendly mode.

Road Transport

Road transport has dominated other modes of transport due to its flexibility and ability to reach out to customers and the security of goods. Indian road network is the second largest in the world spanning more than 5.8 million kilometres. India's road infrastructure has seen constant improvement in last two decades. The seven phased National Highway Development Programme (NHDP) implemented by the National Highway Authority of India (NHAI) is the largest highway development project in the country. Similarly, Prime Minister Gram Sadak Yojna (PMGSY) is the largest rural connectivity program of the country launched in 2000. Formation of NHIDCL in 2014 gave accelerated impetus to speed up the road construction in strategic areas along the international border and North-Eastern region. Project Bharatmala is another program for the highways sector that focuses on optimizing efficiency of freight and passenger movement across the country by bridging critical infrastructure gaps through effective interventions like development of a set of critical economic corridors. In addition, 33 expressways of approximately 15,353 kilometres have been proposed, all of which will further add strength and value to the social and economic developments in the country.

Urban Transport

Urbanization is taking place at a fast rate in India and according to a survey by United Nations for World Population Report, almost 41 percent of the country's population is expected to reside in urban areas by 2030 and urban India is going to contribute 75% of India's GDP by 2030. Even with the current size of urban population, the Indian cities are facing multitude of problems such as congestion, traffic safety, and air pollution due to explosive growth of private vehicles. While the share of urban roads in total road network in the country is less than 10 %, they constitute about 42 % of total road crashes and 35 % of total fatalities.

Road transport dominates in urban areas also. The urban mobility is organized in three broad categories of collective transportation (Public transit system), individual transportation (personal mode and walking) and freight transportation. Public transport is most important component of mobility within urban areas as it provides publicly accessible transport system in a city. Due to inadequate infrastructure for road based public transport system and increased demand caused by urbanization, most of the Indian cities are confronted with problems of traffic congestion, excessive delays at intersections, air pollution and road accidents. Mobility index and congestion factor are two major parameters to assess the road infrastructure in a city. Figure 2 shows these two parameters in selected cities of India. The cities located in top left quadrant experience worst traffic condition (higher congestion, low mobility) while the cities in bottom right quadrant have the best performing road infrastructure (low congestion, higher mobility).

Economic efficiency of the cities is fully dependent on how efficiently the people and goods are able to move throughout the city, and cities are supposed to maintain their competitive edge with growth-oriented positions. Too much delay and indifference towards the development and investment in public transport systems due to the lack of suitable policy, have allowed the undesirable and haphazard growth of low quality intermediate public transport (IPT) systems. Buses are the most popular and convenient mode of transportation in the cities with most extensive network possible; but public transport systems never tried to innovate for the product and services. The continuous decline in patronage of public transport in all cities across India (except Mumbai) has not been able to wake up the policy makers to understand the root cause of this malady, which has severely damaged the cities with serious congestion and road safety problems. As a result, travellers have turned towards personalised modes such as cars and two-wheelers adding more woes to the cities as shown by public transport shares in cities of different sizes, as given in **Table 2**.

Table 2 : Public transport share in Indian cities of different sizes

City size (population)	Present share of Public Transport	Desired share of Public Transport
1 – 2 million	30	60
2 – 5 million	45 – 50	75
More than 5 million	50 – 60	75 – 85

This situation and rising demand further pushed the growth in private vehicle ownership of mopeds, scooters, motorcycles and cars. Thus, India's motor vehicle fleet is extremely skewed towards the very unsafe and highly accident prone two-wheeled motor vehicles with 80% or more in many cities. Moreover, the extremely heterogeneous mix of vehicles sharing the same road space in urban areas has resulted into high accident rate. While the other countries including China have been able to contain this problem of road accidents, India is still facing this serious problem with more than 150,000 fatalities (in 2018) every year, where 62 pedestrians and 10 cyclists were killed daily in 2018.

Introduction of Delhi Metro in 2002 was a major policy intervention to enhance the mobility and simultaneously to ease traffic congestion and air pollution in Delhi and NCR. The city has now a network of 373 km with daily journeys of 5.5 million people in 351 trains. With the success of Delhi metro, a number of cities explored the option of implementing the metro rail project. Currently 21 Indian cities have functional metro rail network and many more are planning for the same. Metro is seen as a viable solution for mass rapid transit system. However, the smaller and medium sized cities are exploring the option of Bus Rapid Transit System (BRTS) and cities like Ahmedabad, Indore, Surat, Pune, etc. already have BRTS in operation.

Future Directions for Transport

Two prime modes of transportation in India are roadways and railways. Unfortunately, these two modes have never communicated with each other in last more than 60 years and are competing with each other. Government of India took a bold decision in 2017 to abandon the practice of presenting a separate budget by the Ministry

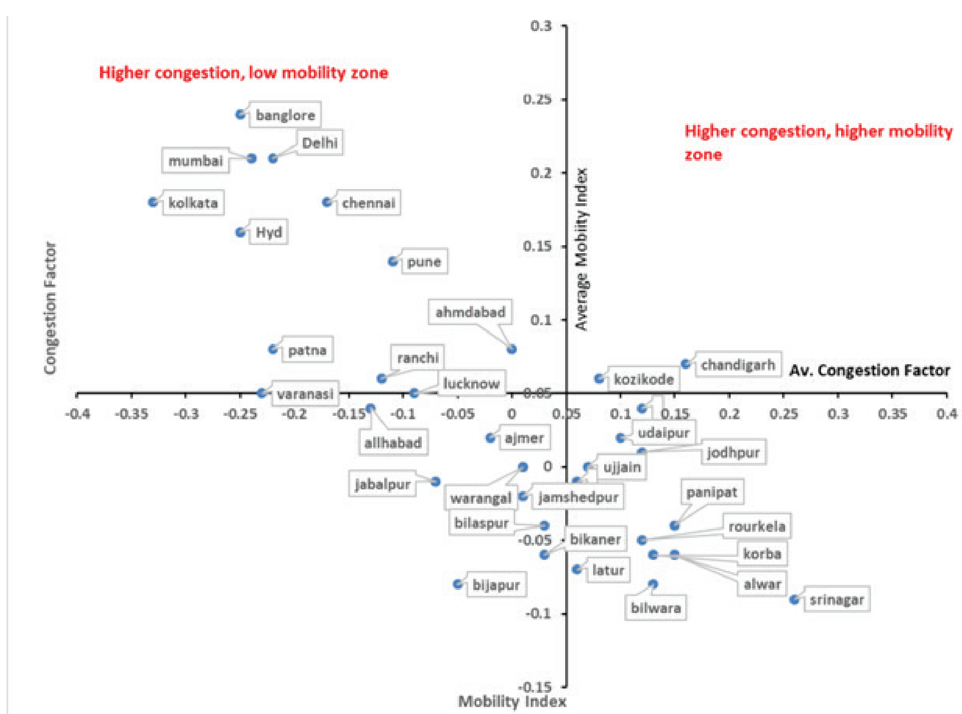

Fig. 2 : Mobility and congestion in selected cities of India

of Railways and made it a part of the general budget. The general budget 2019-20 has given major thrust on infrastructure development in the country with a planned expenditure of Rs. 111 lakh crore (Rs. 111 trillion) during the period 2020-2025. This has a share of 18% for roads, 12 % for rails, 1.0% for ports and airports each and 17% for urban development. Convenient and efficient transportation and logistics are aspirational goals of this investment. Following are the strategies stated for the next five years,

- Enhanced road connectivity to remotest areas with extensive charging and on-road traction infrastructure for e-vehicles
- World class stations and fully integrated rail network with connectivity to remote regions with focus on safety
- Airport and related infrastructure to enable international and regional connectivity so as to achieve passenger and cargo traffic on the vision of National Civil Aviation Policy 2016
- Ports and waterways infrastructure focused on reducing logistics time and cost for foreign and domestic trade as per the Sagarmala National Perspective Plan 2016
- Urban mobility – mass rapid transit system (MRTS) and bus connectivity within 800 m of homes in more than 50 cities.

In support of these, the Government during last five years or so has introduced and adopted several policies for new initiatives to address the growing demand of transport in the future, where the major ones are,

- Revised National Urban Transportation Policy, 2014
- Atal Mission for Rejuvenation and Urban Transformation (AMRUT)
- Automotive Mission Plan (AMP2026)
- National Electric Mobility Mission Plan 2020 (NEMMP 2020)
- Faster Adoption and Manufacturing of Electric/Hybrid (FAME)
- Smart Cities Mission
- National logistics action plan (NLAP)
- Pradhan Mantri Jal Marg Yojna
- Pradhan Mantri Gram Parivahan Yojana & Aajeevika Grameen Express Yojana.

The public transport in Indian cities is characterized as that of high dependency and low availability. The policy initiatives of the Government are likely to change this scenario. However, it is possible only if an integrated transport policy to address problems of urban transport is made. A national policy also needs to be designed to address more environmentally sustainable urban growth, as alienated sectoral policy frameworks do not have the desired impact on urban transportation. If India wants to reduce personal vehicles in its mega cities like Delhi, Mumbai, Hyderabad and Bengaluru, then appropriate policies to address the issues related to manufacturing of cars also need to be formulated. National level policies are also required to drive the multi-modal transport environment for promoting and implementing integrated public transport systems by timely planning of Metro and BRT with special provisions for access modes like bicycle and walking. Implementation and functioning of Unified Metropolitan Transport Authority (UMTA) and Urban Transport Fund (UTF) for their true objectives are the need of the hour to facilitate much needed institutional reforms and integration in development of benign and efficient urban transport systems. With technological advancement in aerial modes, air taxis have been proposed to come up in 2023 by UBER most likely in Mumbai or Delhi. In view of these ideas, GoI has come up with National Drone Policy 2 in 2019 which expands the scope of the operational airspace for drones or similar other vehicles by allowing them to operate beyond the visual line of sight and fly above the current limit of 400 ft.

The unprecedented growth being witnessed in the Indian aviation market, though impressive, is significantly lower than its untapped potential. A nation of nearly 1.35 billion people, with a middle class of over 350 million (and growing) should be flying, at conservative estimates, over 700 million passengers per annum. The 344 million passengers in FY 2019 is a small fraction of that. As per Government's Vision 2040, passenger traffic is expected to increase to 1.1 billion (870 million domestic and 303 million international) in 2040. General aviation will become an integral part of India's aviation eco-system, driven by remote area connectivity, tourism and disaster management programs. The elitist tag and high tax incidence on general aviation should gradually go away. Over the next 5-8 years, all Indian aircrafts will be flying on the satellite-based GAGAN system developed by AAI and ISRO. This will lead to better airspace utilisation and safer operations despite reduced aircraft separation. GAGAN signals will also be used by other sectors like shipping, highways, railways and agriculture etc.

Intercity Transport in Future

The personal mobility for intercity travel in India in 2010 was around 6,000 bpkms, much lower than most developed countries. Driven by increase in population, GDP growth and urbanization, intercity passenger demand is expected to reach nearly 26,000 bpkms by 2050, an increase of 4.3 times relative to 2010. The freight transport in India is also dominated by road, accounting for 59% of freight movement, while 35% of demand is met by rail, 6% by waterways and less than 1% by air. Approximately 1.1 billion metric tons of freight was carried by Indian railways in the fiscal year 2017, whereas over 2.2 billion metric tons of freight was moved by road transport across India in the same year, indicating a very low share of Railways. In the BAU (Business As Usual) scenario, the overall demand for freight transport is expected to be 10,052 billion ton-km in 2050, and in terms of mode shares, not much change is expected, and road and rail will continue to be the main modes of transport for freights. A road-based transport system poses a serious challenge of national energy security and greenhouse gas emissions. Railway on the other hand, provides energy efficient and low emission transport system, and therefore, the intercity travel in future must be dominated by railways. Recently, the Ministry of Railways, Government of India, has formed the High Speed Rail Corporation of India Limited (HSRC) for the development and implementation of high-speed rail projects. Various types of intercity transport systems that are expected for the movement of passengers and freight in future are discussed in the following subsections.

Rail Transport

High Speed Rail

Magnetic levitation (or maglev) or wheel based High Speed rail (HSR) technology has been around for decades, but for commercial use it has been only in a few countries. High speed rail system development was in focus throughout the last two centuries and achieved a speed of about 300kmph in Western Europe and Japan as well as in a few other countries. The fastest commercial High Speed Rail system in Shanghai uses magnetic levitation technology and can go up to 431 km/hr. This technology is going to dictate intercity travel in many countries including the UK, Germany, USA, China, India, and Malaysia in next 20-25 years. HSR are good substitute for conventional railway services on routes where high capacity is required, to reduce travel time, and to improve the railway services against other modes. This can help address future travel demands, reduce congestion along major corridors, and expected to achieve the simultaneous benefits of improved mobility and economic development along a transport corridor, along with energy efficiency and mitigation of climate change effect.

High Speed Rail Corporation of India Ltd (HSRC) was established in 2013 by RVNL to implement the proposed high-speed rail corridor projects under PPP mode on DBFOT basis. The proposed high-speed rail is expected to run at 320-350 km/h.

The first HSR planned is between Mumbai and Ahmedabad (proposed to be completed by 2021 as per feasibility report). The proposed HSR corridors as per HSRC are,

- Delhi-Jaipur-Jodhpur (530 km)
- Pune-Mumbai-Ahmedabad (680 km)
- Trivandrum-Ernakulam-Bengaluru-Chennai (1020 km)
- Chennai-Vijaywada-Dornakal-Hyderabad (780 km)
- Delhi-Agra-Lucknow-Varanasi-Patna (1000 km)
- Delhi-Chandigarh-Amritsar (480 km)
- Howrah-Kolkata-Haldia (140 km).

The proposed HSR routes in India for its first phase development are presented in **Fig. 3**.

Dedicated Freight Corridors

The 10,122 km long Golden Quadrilateral, connecting the four metropolitan cities of Delhi, Mumbai, Chennai and Kolkata, along with its two diagonals (Delhi-Chennai and Mumbai-Kolkata) constitutes 16% of the Indian Railway (IR) network. It carries 52% of the passenger traffic and 58% of the freight traffic. Accordingly, under the Eleventh Five Year Plan of India (2007–12), the Ministry of Railways started constructing two Dedicated Freight Corridors (DFC), Western and Eastern DFCs of total length of 3,360 kilometres. The Corporation DFCCIL has been designated by Government as a 'special purpose vehicle' for development of DFCs. During last few years, the railway freight traffic has grown by 8 to 11%, which was projected to cross 1100 million tonnes by the end of 11th Five Year Plan. Indian economy is highly dependent on a few core sectors, and in turn they have a greater dependence on railways, and therefore, in supporting these core sectors, a target of 1850 million tonnes of freight traffic was envisaged in 2020. Four other DFCs were announced in the railway budget of 2016 and later

Fig. 3 : Proposed HSR routes in India

approved with funds allocation. The six corridors are listed below.

- Western Dedicated Freight Corridor (WDFC), 1,468 km from Dadri in Uttar Pradesh to Jawaharlal Nehru Port in Mumbai
- Eastern Dedicated Freight Corridor, Ludhiana, 1,760 km from Punjab to Dankuni in West Bengal
- East-West Dedicated Freight Corridor (WDFC), 2,000 km from Kolkata to Mumbai
- North-South Dedicated Freight Corridor, 2,173 km from Delhi to Chennai
- East Coast Dedicated Freight Corridor, 1,100 km from Kharagpur to Vijayawada
- South-West Dedicated Freight Corridor, 890 km from Chennai to Goa

The DFCs were launched to reduce unit cost of transportation by speeding up freight trains for higher productivity, increase rail share in freight market, segregate freight infrastructure for focused approach on both passenger and freight business, create additional rail infrastructure to cater high levels of transport demand. It is expected that the DFCs will be the game changer for Railways in the freight segment of intercity freight movement, and they will free-up capacity on dense passenger routes and will allow Railways to run more trains and at higher speed.

Rapid Rail Transit Systems (RRTS)

Rapid Rail Transit Systems (RRTS) is a new, dedicated, high speed, high capacity, comfortable commuter rail service connecting regional city nodes. RRTS is different from conventional suburban rail (EMU services) as it provides comfortable, reliable, high frequency, point to point regional travel mode at high speed along dedicated corridors. RRTS is different from metro also as it caters to passengers (intercity) demanding to travel relatively longer distance with fewer stops and at higher speed. Eight corridors have been identified in India for construction of RRTS and the work on three corridors namely Delhi-Meerut, Delhi-Panipat and Delhi-Alwar have already started. The representative image of RRTS and proposed RRTS corridors in NCR are given in **Figs. 4 and 5** respectively.

Water Transport

Pradhan Mantri Jal Marg Yojna, 2017 aims to convert 101 rivers in India to National Waterways, whereas presently India has only five National Waterways which are operational. The 2016 National Waterway Act was enacted to regulate the development of 111 national waterways including five operational waterways. Currently, India is using water transport for only 3.5% of freight transport through waterborne transport, compared to 47% in China; 40% in Europe; 44% in Japan and Korea; and 35% in Bangladesh.

The Jal Marg Yojana also seeks to develop new dry and wet ports. Initially, the plan aims to enable commercial navigation of vessels with capacity

Fig. 4 : Rapid Rail Transit Systems (RRTS) for intercity travel

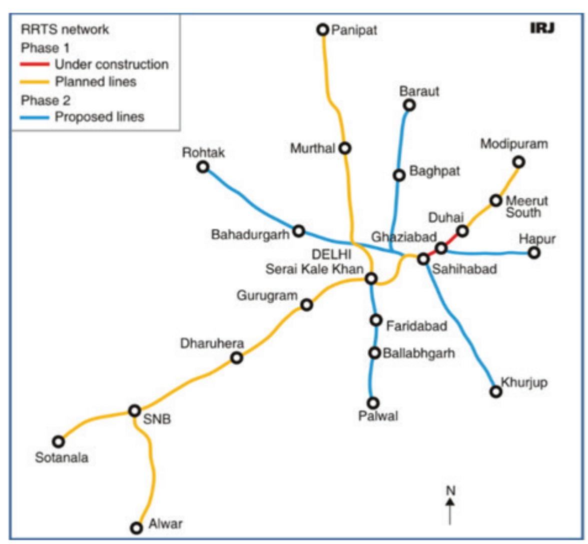

Fig. 5 : Proposed network of RRTS for intercity travel in NCR

of 1500 – 2000 tons in National Waterways-1 with construction of 4 Multi-Modal Terminals (at Varanasi, Sahibgunj, Haldia and Gazipur), implementation of River Information System (RIS) for a sustainable river navigation system, Digital Global Positioning System (DGPS), night navigation facilities, and construction of navigational lock at Farakka.

The Government has also taken up a project called Sagarmala, which along with development of ports, also supports augmentation of National Waterways for commercial use. As part of the programme, a National Perspective Plan (NPP) for the comprehensive development of India's 7,500 km coastline, 14,500 km of potentially navigable waterways and maritime sector has been prepared. As part of this project, short term objectives involve even creation of a separate toll lane for EXIM cargo only so that transfer of goods takes less time. As part of Sagarmala, many projects have been identified for implementation during 2015-2035 in the areas of port modernization and new port development, port connectivity enhancement, port-linked industrialization and coastal community development.

Road Transport

Roads/Highways

The Government has taken up the Bharatmala Pariyojana in 2017 to improve and modernise the road network in the country, the budget for which will be managed by the cess collected on petrol and diesel and the tax collected at toll booths, apart from the budgetary support. The program had identified around 26,200 km of Economic Corridors or routes that have heavy freight traffic. Its objective was to improve efficiency of existing corridors through development of Multimodal Logistics Parks and elimination of choke points. It also focused on improving road connectivity in North-East and creating seamless connectivity with the neighbouring countries. A total of 550 districts are expected to be covered under this project. The main components of Bharatmala Pariyojana are,

- Development of Economic corridors – 9,000 km
- Inter-corridor & Feeder roads – 6,000 km
- Improving the efficiency of National Corridors – 5,000 km
- Border & International connectivity roads – 2,000 km
- Coastal & Port connectivity roads – 2,000 km
- Expressways – 800 km
- Balance of NHDP works – 10000 km

The project plan includes the construction of Border Roads of strategic importance along international boundaries and International Connectivity roads to promote trade with Myanmar, Bangladesh, Bhutan, and Nepal. It is a massive highway development/up gradation programme involving 42,000 km of roads with 44 economic corridors, 66 inter corridor routes and 116 feeder routes along with development of 24 multi-modal logistic parks, interventions for 185 choke points with ring roads/bypasses for cities and other appropriate interventions as well as 24 integrated check posts for borders.

National Infrastructure Pipeline (NIP)

India is currently ranked 70 out of 140 countries for infrastructure quality in the Global Competitiveness Index, and ranked 72 in case of road connectivity. Infrastructure is the catalyst to raise the quality of life and standard of living in the country, as deficiencies in infrastructure is the primary growth constraint. The four significant economies in terms of GDP in PPP terms from now until 2050 is shown in the **Fig. 6**, which shows India to be second only to China. The Roads & Bridges sector had a share of 18% only in the total investment of Rs. 57 lakh crores during 2013 to 2019. The total sector-wise break up of NIP investment during 2020-25 has been earmarked as 2 million crores, second only to Power sector.

India's ambition of sustaining its relatively high growth depends only on smart infrastructure, and therefore, efficiency of transport infrastructure

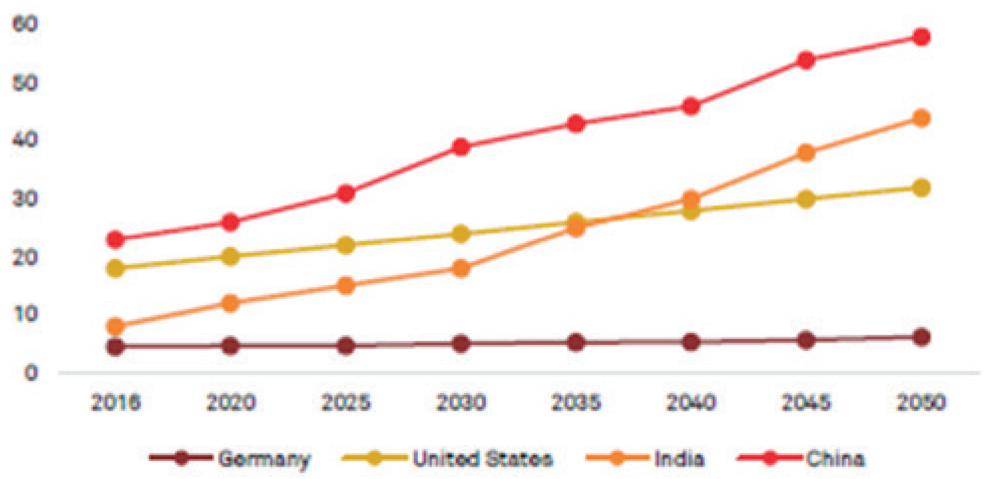

Fig. 6 : GDP in PPP terms ($ trillion)

delivery and services, particularly for the road sector shall have to be maintained.

Expressways

National Highways Authority of India (NHAI) is mandated to implement National Highways Development Project (NHDP) in a phased manner. Also, the Ministry of Road Transport and Highways is in the process of preparing a draft for creation of a National Expressways Authority of India (NEAI) on the lines of the NHAI. Expressways are the highest category of roads with controlled access, and size of the expressway network in a country defines mobility advantage. Currently, approximately 1,650 km of expressways are operational with six or more-lanes as controlled-access highways where entrance and exit are controlled through appropriately designed interchanges. Approximately 7,800 km of expressways are under construction and another 7,350 km are under planning stage. India has one of the lowest densities of expressways in the world. The NHDP and Bharatmala programmes aim to expand the country's current expressway network and plans to add an additional 18,637 km of green field expressways apart from existing multi-lane national highways. Access controlled expressways provide high speed corridors and are the future of road based intercity movement of passenger and freight traffic. Some of these proposed major expressways are as follows:

- Delhi-Amritsar-Katra (670km)
- Ganga Expressway (1,047km)
- Nagpur-Hyderabad-Bengaluru (1,100km)
- Narmada Expressway (1,300km)
- Mumbai-Nagpur (766km)
- Varanasi-Ranchi-Kolkata (650km)
- Pune-Bengaluru (745km)
- Delhi-Mumbai (1,250km)
- Brahmaputra Expressway (890km).

Hyperloop

Transportation technology like hyperloop can transport many people to a great distance in a nick of time. A hyperloop is an ultra-high-speed ground (or underground) transportation system akin to bullet trains. The principle of the Hyperloop is based on the movement of people in capsules or pods that travel at high speeds though tubes with low pressure environment void of air, while the pods use magnetic levitation (MagLev) technology for propulsion. The Hyperloop resembles a vactrain system but operates at approximately one millibar (100 Pa) of pressure. The low pressure and MagLev, create a very low friction environment allowing the pods to travel at 1000km/h and more speed which would account for a faster and cheaper travel than traditional road, rail, and air travel. They are quicker and cheaper to build than traditional high speed rail and also cause less pollution than air travel, while taking the pressure off the roads and thereby making travel between cities easier and potentially unlocking major economic benefits as a result. The MAGLEV / hyperloop technologies underline that certain countries can leap-frog to circumvent transport technology and adopt directly a new one, as several developing economies have avoided the setting up of wire-based telecommunication networks to move directly to cellular networks. A similar trend could apply to the MAGLEV / hyperloop technologies circumventing conventional high speed rail systems.

The Maharashtra government gave the final nod for constructing a 200 kilometre hyperloop between Mumbai and Pune, and it is expected to slash the 3.5 hour travel time between the two cities to 35 minutes. The hyperloop system will be a real energy and time-saver. A feasibility analysis estimates that hyperloop routes could be up to six times more energy-efficient than air travel on short routes, and over three times faster than the world's fastest high-speed rail system. A typical hyperloop transportation system is shown in **Fig. 7**.

Low pressure Hyperloop tube

Artist's concept of Hyperloop

Fig. 7: Typical Hyperloop transportation system

Some of the hyperloop projects in India, which are actively considered and are at different stages of study and development are: Mumbai – Pune (200 km in 35 min), Amritsar - Ludhiana - Chandigarh (233 km in 30 min), New Delhi - Mumbai (via Jaipur and Indore 1,317 km in 55 min), Mumbai - Bengaluru - Chennai (334 km in 20 min), Bengaluru - Thiruvanathapuram (736 km in 41 min).

SkyTran

The SkyTran is a 'third-generation' Personal Rapid Transit (PRT) technology, which hopes to change the face of inter-city public transport across the world. A driverless automated that operates on overhead suspension or magnetic levitation on the user's personalised route directly to the destination non-stop. SkyTran will have a network of computer controlled levitating 'jet-like' vehicles, which will transport passengers above surface traffic at a speed of 250 km/h. In India, several states are exploring this option and currently PRT opportunities being explored for Rajasthan, Bihar, Jharkhand and Kerala. At the normal operating speed of travel on intercity routes a journey between Delhi and Chandigarh or Delhi to Jaipur would just take an hour. A view of possible SkyTran system is given in **Fig. 8**.

App-based Aggregators for Cab and Bus

Intercity road travel in India is five times bigger than railways and business by road is mainly divided among bus and taxi service providers. The intercity taxi market in India is estimated to be over Rs 60,000 crores, with an annual growth of 15-18%. However, more than 90% of this

Fig. 8: Futuristic representation of SkyTran

market is unorganised. There is a serious issue of taxi service providers charging inflated fare for one-way travel, and because of that many will opt for a luxury bus ride instead. The future intercity travel will be using App-based taxi aggregator service, which will charge one-way fare only for one-way movement and will allow ride sharing to make the fare more economical.

Other Innovative Transportation Systems

String theory is a set of attempts to model the four known fundamental interactions: gravitation, electromagnetism, strong nuclear force, and weak nuclear force, together in one theory. This theory is very common in quantum physics, but it can become a good tool to define future transportation between the cities. The concept, named as 'String Theory based Transportation' is based on the use of two strings with a wheeled vehicle riding on them. It is a new low-cost transport system, and it can go through everything water, deserts or forests, towers. An example of this is shown in **Fig. 9**.

Among driverless vehicles on highways, self-driving trucks may offer the most significant potential. In a setting where well defined highways and stable driving conditions are prone to automation, trucks are able to coordinate their respective mobility by assembling convoys (or platoons) where each vehicle follows the other closely, thereby reducing fuel consumption. They also have the potential to service repetitive short distance hauls such as between terminals like ports and rail yards and distribution centers. Implementation of automated trucks is likely to be route specific and incremental in nature. They are being already used at port terminals to move containers between docks and stacking yards. Such an automated truck is shown in **Fig. 10**.

Future of Urban Transport

Urbanization is a global phenomenon without exception of India, as productivity/efficiency of urban areas along with quality of life draws population from the hinterlands, and at present 50% of world's population live in cities. In 2011, India had 377 million people living in 468 urban areas with population above 0.1 million, where 53 cities had more than 1 million population (which was 31% of total population). India is likely to have 500 million urban population by 2021 itself and it will have 42% population living in urban areas by 2030 (and 58%, i.e. 875 million by 2050). It is estimated that almost 70% of world population will live in cities by 2050. The population across cities of various sizes has

Fig. 9 : String theory based transportation

Fig. 10 : Self driving truck from Volvo

a skewed distribution with more population for the cities with million-plus metropolitan cities. Thus, in such cities urbanization is expected to increase average city density by 30 percent over the next 15 years, and therefore the planners and residents are putting liveability and sustainability issues now much higher on their agendas. With increasing population the cities' already strained urban transport infrastructure and services are expected to deteriorate further in terms of congestion and pollution. For the lack of transport infrastructure and services, often the very process of urbanization feels to be undesirable.

With the introduction of National Urban Transport Policy (NUTP, 2006) and JnNURM (a National Mission from 2005), a massive initiative was there using national funds for creating much-needed infrastructure of urban areas, where buses were recognised to be much higher in urban transport context, till every city vied for the image building with Metro systems. The so called 'poor man's metro', flourishing world over, the BRT system has been defamed in India with a designed failure in Delhi, and uniformly poor implementation everywhere else, except in Ahmedabad, and then all are limping with limited success and acceptance in several cities in India. In 2015 the government unveiled its 'flagship' plan to upgrade 100 cities to 'smart cities' and to 'renew' 500 cities (with Atal Mission for Rejuvenation and Urban Transformation: AMRUT), which was to address urban transport as well, but in most cases it was like routine projects (e.g. off-street parking, street lights, signalisation of junctions, etc) that could not be taken up earlier for want of financial resources, and thus not measuring up to the objectives of the smart cities mission.

Modes of Urban Transport (Passenger and Goods)

The transport in urban areas cannot be fully characterised only by consideration of passenger travel alone. Most urban areas invariably have a very wide variety of modes for passenger and goods movement within the urban area, and in India some of which are prima-facie informal modes developed due to deficient policies. Though the primary objective of this paper is for passenger travel, the entire gamut of urban modes are listed here for giving a real feel of the complexity of urban transport in India.

(a) Private passenger transport modes

- (i) Pedestrians – with or without footpath
- (ii) Bicycles – with or without bicycle lane
- (iii) Motorcycle, Scooter, Moped – all motorised 2-wheeters
- (iv) Private cars, motorised 4 wheeled vehicles – small, medium and big cars and SUVs.

(b) Public transport modes

- (i) Intermediate public transport
  - Cycle Rickshaw, including some motorised cycle rickshaw
  - Auto Rickshaw – motorised 3-Wheeler vehicles
  - E-Rickshaw–Battery operated motorised rickshaw
  - Normal city taxi cabs
  - Taxi aggregators (like OLA, UBER, etc)
  - 3-Wheeler Passenger Tempo Traveller – various sizes and makes
  - 4-wheeler Passenger IPT vehicles - various sizes and makes (e.g. Grameen Sewa, Phat-Phat Sewa, and so on)
  - Tractor with trolley.
- (ii) Formal public transport
  - Bus (Minibus, regular bus, articulated-bus, double-decker bus, low-floor bus)
  - Bus Rapid Transit (BRT), Trolley Buses, Busway
  - Tramway/Streetcars (primitive and modern tram)

- Light rail transit
- Metro Rail – Underground, on ground, and elevated
- Regional taxi, including urban area taxi services
- Suburban Train (EMU) services
- Rail Rapid Transit (RRT)
- Monorail.

(c) Goods transport modes

- Push Cart (with 4 wheels) for goods carrying
- Cycle Rickshaw Cart for goods – some are motorised
- Motorised 3-Wheeler Goods Tempo Traveller - various sizes and makes
- E-Rickshaw Goods Tempo - Battery operated motorised rickshaw
- Motorised 4-wheeler Goods Trucks (Micro) - various sizes and makes
- Light Commercial Vehicle (LCV: Truck) - various sizes and makes
- 2-Axle/3-Axle Single Unit Truck - various sizes and makes
- Multi-Axle Trucks - various sizes and makes
- Prime Mover Truck for Container Transport - various sizes and makes
- Truck with Trailer - various sizes and makes
- Tractor with trolley.

Multiplicities of modes (both passenger and goods) in urban areas and with totally uncoordinated and unregulated operations have completely damaged the character of urban transport with total absence of quality and efficiency. To handle urban travel demand in cities, many a times demand management was considered to be apt, while in this paper the objective is not to suppress demand but to handle it more efficiently with adoption of technology and provision of appropriate infrastructure – both hard and soft. Upgradation and introduction of high speed, high capacity public transport systems particularly along high density corridors need to be planned and implemented early enough to maintain the preference of public transport for the population. In real sense, urban transport planning in India had been absent in any logical sense due to inherent asymmetry (power, information, resources) amongst the agencies or totally disintegrated with absence of cooperative approach of the institutions which manage the urban areas. The central government also had earmarked INR 100 billion (US$ 1.5 billion) for metro projects in the budget of 2016-2017, as a result of which about 316 km of metro lines currently in operation today and more than 500 km of metro lines under construction across various cities in the country.

Beginning of the 21st century saw some concerted but yet uncoordinated efforts by the central and state governments to increase supply through building flyovers, purchase of bus fleets, and through investments for BRT, Metro, and commuter rail system, etc, some of which aggravated the problems as many of these were attempted like quick-fix solution without legitimate planning and citizen participation and there was parallel fast growth of vehicle ownerships. All these have proved adequately that mere proclamation of policy (i.e. NUTP) and intent is insufficient without focus on sustainability and associated financing muscle. Moreover, the basic need of building institution for urban transport (like UMTA) was always avoided or bypassed in favour of disintegrated authority. Integrated systems for seamless mobility are the most radical departure from today's reality of the absence of any coordination or integration of urban transport modes. Many world cities, including mega cities in India, have also grown with sprawl, where autonomous private modes and mass rapid transit may be required to meet the modern day mobility needs. Further, studies have shown that clean and shared mobility using electric vehicles is the only option with densely populated cities like Delhi, Mexico City, Mumbai and other similar cities.

While most of the private passenger modes and the intermediate public transport modes exist in most cities in India, the formal public transport using buses exists only in major cities with exception of a few other non-metropolitan cities. The Rainbow BRTS in Pune is the first BRTS system in the country, while the more successful Ahmedabad Bus Rapid Transit System started in 2009. Other BRT systems implemented, but not so successful, are for Jaipur, Vijayawada, Rajkot, Surat, Indore, Bhubaneswar, Jodhpur, Raipur, Vishakhapatnam, Amritsar, Bhopal and Hubli. Further, a few other cities are vying for BRTS, which are Kolkata, Mumbai, Chennai, Coimbatore, Hyderabad, Madurai, Tiruchirappalli and Guwahati.

The operational suburban rail systems exist in Mumbai, Kolkata, Lucknow-Kanpur, Chennai, Delhi, Pune, Hyderabad, Barabanki-Lucknow and Karwar, while a few like Bengaluru, Ahmedabad and Coimbatore are being planned. The first modern rapid transit was implemented in Kolkata in 1984 and thereafter Delhi Metro in 2002 and Namma Metro (Bangalore) in 2011. Other operational Metro are in Gurugram, Mumbai, Jaipur, Chennai, Kochi, Lucknow, Nagpur and Hyderabad. Other Metro systems planned are in Noida, Ghaziabad, Navi Mumbai, Nagpur, Gandhinagar, Ahmedabad, Varanasi, Kanpur, Bareilly, Pune, Vijayawada, Patna, Meerut, Guwahati, Chandigarh, Bhopal, Kozhikode, Indore, Thiruvananthapuram, Agra, Coimbatore, Visakhapatnam, Surat, Srinagar, Greater Gwalior, Jabalpur, Greater Nashik, Bengaluru, Kolkata and Delhi; some of which are actually Light Rail Transit being developed as feeder system to Metro. Mumbai Monorail started in 2014 and some more systems are being planned in Chennai, Kolkata, Allahabad, Bengaluru, Delhi, Indore, Kanpur, Navi Mumbai, Patna, Pune, Ahmedabad, Aizawl, Bhubaneswar, Jodhpur, Kota, Nagpur and Nashik. Also, Kolkata has the only tram system in the country in operation.

Requirements of Changing Mobility

Mobility is the lifeblood of cities and traditional mobility patterns are changing. Technological innovations in the form of electrification, digital connectivity, and autonomy are on the horizon to change/disrupt the existing social, economic, and technological trends for urban mobility. Individual cities will make different decisions, based on specific local conditions, and go in different directions with potential to demonstrate the profound effects of mobility innovation for new city dynamism, and the mobility systems of the future are likely to be very different from what exists in most of the world today. The individual traveller is at the heart of this evolution, and both the public and private sectors will have roles to play in paving the way for it. By developing fully integrated systems of urban transport, opportunity for seamless mobility through various modes (private, shared and public modes) of transport will be possible to handle all types of urban travel and higher levels of demand. In an integrated system for seamless-mobility, people would potentially travel 20 to 50 percent more, because it is cheap and easy, and EVs (electric vehicles) could account for as many as two-thirds of vehicles on the road. With ridesharing growing up, digital vehicle connectivity deepens its roots, EVs becoming mainstream, travellers would have a variety of clean, cheap, and flexible means of travel. The city planners/engineers and urban-mobility specialists must try to achieve this vision of urban transport in the future.

MoUD had provided financial assistance to 11 cities for the construction of 504 km Bus Rapid Transit System (BRTS). The central government has also unveiled an ambitious project to replace all public bus transport fleets with hybrid technology converting existing conventional fuel buses into electric buses. Further, IT solutions are very important for public transport systems and thee tools only can help to improve operation and efficiency making it a smart transportation system. Most of the cities' bus systems are still lagging behind in the implementation of an IT system, and even Smart Mobility Card could not be implemented in most of the cities easily as an inter-operable smartcard. Moreover the City Transport Corporations had struggled for very long for roll-out of a planned integrated system of transport, where all modes of urban transport need to be integrated for legitimate opportunity to traveller for sustainable future. A scenario of modes in an Indian city with share in travel is shown in **Fig. 11**.

The technology driven capacity utilisation of the available systems also can provide the initial relief through (i) technology interventions of existing public transit modes, (ii) intelligent transport system across the board, and (iii) adoption of smart parking technologies. Other demand management options that can be adopted in the short- and medium-term interim periods are like (i) dedicated lanes for shared modes, (ii) changing to e-scooters and e-bicycles, (iii) making shared and off-peak travel more attractive, and (iv) shifting all commercial deliveries to off-peak hours. These are likely to provide about 20% relief in congestion and pollution.

Future of Mobility in Urban Areas

Predicting the future is perilous and it is true in respect of changes in mobility systems even for the next 10 to 15 years. One of the pitfalls in attempt to predict future in transport involves technology that already exists with extrapolation of capabilities, and what is considered plausible is unlikely to become a reality, if the extrapolation is long into the future. This common mismatch in predicting future is demonstrated in **Fig. 12**.

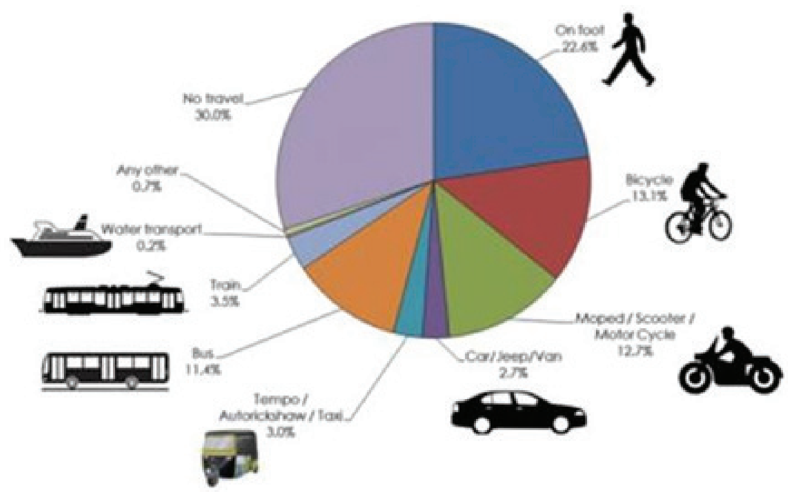

Fig. 11 : Share of urban modes in work trips in 2011 – An example

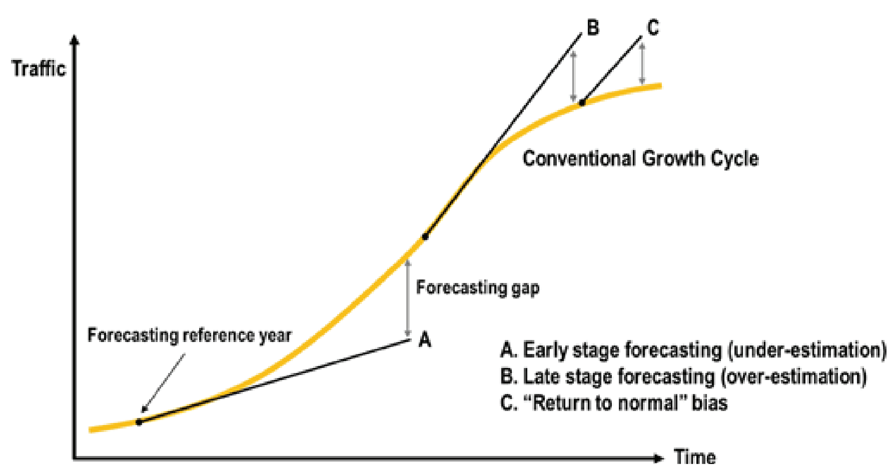

Fig. 12: Flaws in forecasting of future transportation systems

A small number of cities today, such as Amsterdam, Singapore, and Stockholm, are singled out as having effective mobility as they have, with varying degree of emphasis, efficient public transit, cycling and walking encouraged, and have managed to limit congestion and pollution. In cities from Tokyo to Vancouver, the reality of changing mobility is already apparent. It is so because, getting mobility right could be a significant competitive advantage for cities with clean air and reduced road deaths, which is also an opportunity to improve the quality of life. With business-as-usual and the continued urbanization, the demand will increase by 15% by 2030. While the western world is preparing for shared autonomous vehicles or robo-taxis by 2030, the policy and infrastructure in India may not be able to adopt those yet. However, the electric vehicle policy is pushed by the Government may see large proportion of vehicles to be EVs by next 5 years. All 2-wheelers are proposed to be EVs by 2023 or sooner only.

Infrastructure is recognized as an enabler for growth and this only can shape the better future, and which only can provide better quality of life in global standards. National Infrastructure Pipeline (NIP), a strategic project for multiple infrastructure domains, with projected infrastructure investment of Rs 111 lakh crore during FY 2020-25, prepared by a task force of senior bureaucrats only, has many possibilities for urban transport infrastructures along with seven other significant areas of infrastructure developments, only if these investments (projects) are guided by proper technical studies for their legitimate objectives. One of the eight special areas of NIP is 'Convenient and efficient transportation and logistics', which aims sustainable urban mobility for competitive advantage of cities by provision of mass rapid transit system (MRTS) and bus connectivity within 800 m of homes in more than 50 cities. NIP also aims to have smart city infrastructures for sustainable mobility ensuring safety, and all urban infrastructures together is promised about 20 lakh crores during the five years.

The Government resources may not be able to transform the vision of future mobility, and it has to be public-private partnership initiatives. However, economic and market forces would always orient towards most efficient form of transportation system based on prevailing input conditions and cost effectiveness as described in **Fig. 13**.

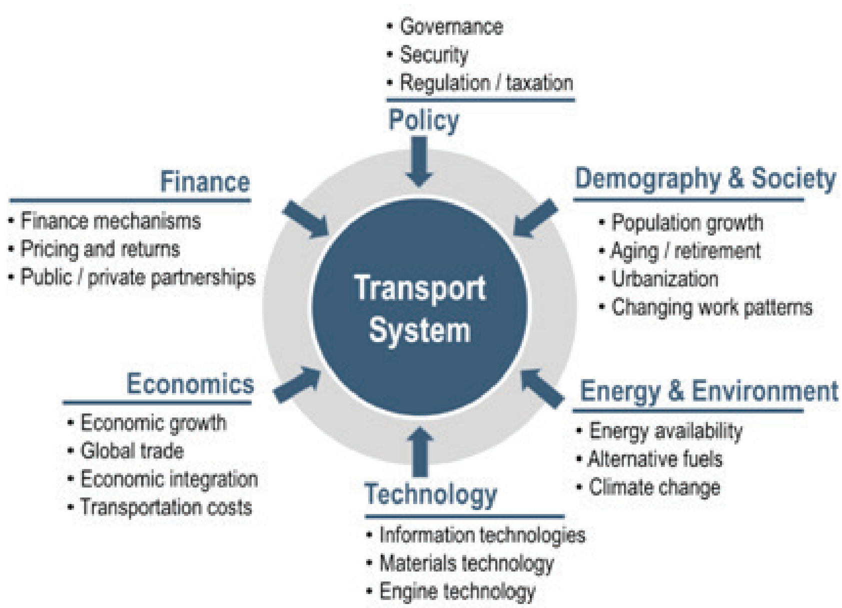

Fig. 13: Drivers of change for future transportation

In 2017 the NitiAayog produced a report on 'Transformative Mobility' for the future in India giving a prescriptive direction for mobility transformation with integrated systems, shared-connected mobility and electric vehicles in a 15 year horizon until 2032, as shown in **Fig. 14**. Adoption of such transformation is shown to have expected reduction in the energy demand by 64% and carbon emission by 37%. Though the notion adopted is for leapfrogging, the ground realities are to be given a chance to change in some way for the visionary goal, which is missing. The quantity and quality of infrastructure for transport available in the cities and also outside cities at this time does not show any immediate opportunity for realising any of the new paradigms fully and may be even for next 10-15 years. Of course, 'pockets of excellence' are plenty in India without general excellence everywhere. The reason for this is the lack of strong policies and clear understanding (of the steps to be followed) in those who matters for this shift in the paradigm. Of course, the forced interventions in each of these elements can create some examples only, but that will not be matching with the vision of transformed mobility. Even today, these three paradigms are not new in Indian cities, but yet there is 66% share of the personalised modes, and there is no reality check on that.

Urban Transport Systems in Future

Three concepts will be driving the future of transportation, especially for the urban transport: smart technology, electrification and autonomy. The transformative technologies will set the next innovation in the transportation sector that will describe how we live and perform our day to day activities. Thus, the 'mobility revolution' is going to aim for the three zeros: zero emissions, zero accidents and zero ownership. While there were 800 cars per 1000 population in USA in 2014 and Delhi has now about 300+ motor vehicles per 1000 population, the ownership is going to decline fast in preference to shared and on-demand modes. It is already established that the most powerful tool for mobility is the smartphone. Thus, a transportation revolution has begun with expansion and deepening of digital trends like big data analytics, IoT and zero emission technologies to provide for cleaner and more efficient methods of transportation. For transport to become truly customised, consumers will need to be comfortable sharing massive amount of personal data, as the data security is far from assured at this time.

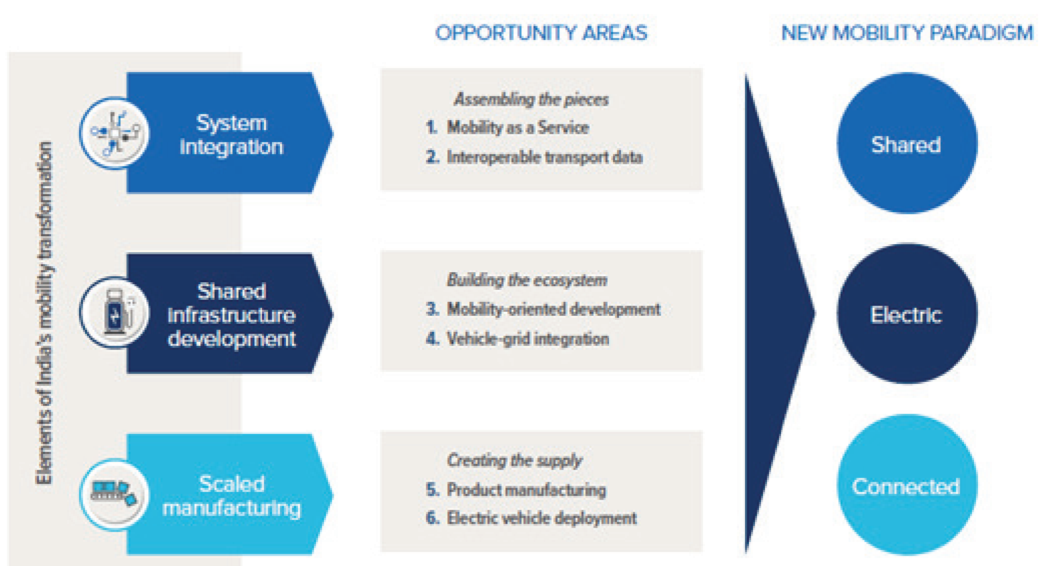

Fig. 14 : New mobility paradigms for future

The urban transportation systems in India needs modernisation with strong reforms in institutional systems required for integrated and coordinated systems with clearly define policies and priorities of multiple modes in an urban environment for affordability to all sections of the society along with ample choices for all. The key concepts of technology and industry driven service products must guide the developments in urban transport with a long term vision of at least 20-25 years. The revised NUTP in 2014 provided policy guidelines for urban transport as part of urban planning and strict focus on transit oriented development along with enhanced role of NMT modes in urban transport. National Electric Mobility Mission (NEMM) of 2013 targeted sale of 6-7 million of electric and hybrid vehicles in India every year by 2020 with cess and GST benefits, signalling India's commitment to transforming its mobility system. Similarly, the programme of Faster Adoption and Manufacturing of Electric/Hybrid (FAME) aims to electrify public transport and all shared intermediate public transport modes (like 3-wheelers and 4-wheelers). These policies and programmes along with the global ideas identified in earlier sections are going to change the future mobility scenario in urban India. In India dual fuel vehicles also have gained popularity and electric, hybrid electric and fuel cell vehicles seem to be the future of vehicle technology. The Indian market for electric vehicles is still nascent as the challenge remains in augmentation of charging infrastructure in big cities and promotion of migration to electric vehicles.

A new paradigm shift is triggering the transformation using information and communication technologies (ICT) to improve the speed, efficiency, safety, and reliability of mobility along with complete or partial automation. The global positioning systems, sensors, and mobile communication technologies are shaping up the emergence of on-demand mobility services creating a hybrid operational model. At the beginning of the 20th century nobody would have been able to even dream of what transportation would look like at the beginning of the 21st century. Since huge technological innovations took place in the 20th century and that the laws of physics are much better understood, the humanity is posed for a dramatic shift from the love for personalised modes of transport. However, the socioeconomic impacts of such technologies and systems remain highly complex to assess, and rarely lead to accurate assessments. Smart technology based shared/connected modes, also known to be on-demand transport, where ICT based ITS with secured personal data systems with strong V2V and V2I (Vehicle to Vehicle and Vehicle to Infrastructure) connectivity and information exchange for safety and efficiency shall be future of urban transport as a new normal. Driverless or automated vehicles are a further evolution of the integration of above systems into transportation. However, in an urban setting, consideration of a large number of safety factors makes such implementation more of a social than a technological constraint. Examples of autonomous car, bus and trucks are already in existence, as shown in **Fig. 15**.

Fig. 15 : Autonomous car and bus, as already developed

Urban Light Transport System (ULTra) is an automated light transit system and a form of rapid transit, composed of small vehicles of a maximum of 4 passengers, which operate on special right-of-way either on ground or elevated. The vehicle is on-demand, semi-private, and will service only the requested destination bypassing all the stations in between, which creates flexibility and privacy which are lacking in standard mass transit systems. The first commercial application of the technology was applied in 2011 at the Heathrow International Airport in London, as shown in **Fig. 16**. The other notable development is automated urban transport pods which would seat one person and move over a pre-described route. Passenger will interact with the pod by touchscreen on the windshield. Such pods are already made use of in Masdar city in Abu Dhabi and also at the Heathrow International Airport in London, as described above (shown in **Fig. 17**). Automated

Fig. 16: Urban Light Transport (ULTra) system

Fig. 17 : Urban transport pod

car, bus and truck are also already developed and tested in some of the developed countries.

Other important derivatives from these innovations are far reaching, such as the driverless vehicles are likely to improve the mobility of marginal groups (e.g., elderly people and people with disabilities). Also, the replacement of materials like iron and steel with carbon fiber and magnesium-aluminium alloy would make vehicles lighter to provide 6% fuel efficiency for every reduction of weight by 10%. Moreover, autonomous flying taxis, also called electric air taxis and Hoverbikes with VTOL platform, which are considered to be one of the major futuristic innovations of the transportation industry, have already been tested. When commercialized, they are expected to ease the traffic burden on city roads transporting people from one place to another. Another category of automated vehicles are drones and their usage may range from monitoring and inspection of infrastructure facilities to faster delivery of light weight packages, which is already being used by the E-commerce giants.

The other development in transport is the electrification of all public transport and IPT systems, including the personalised modes like e-scooter and motorcycles. The post-Covid initiative is also attempting to provide e-Bicycle for a significant shift to old NMT modes for avoiding the crowded normal public transport. Even the normal Bicycle-share programs offer a sustainable alternative in reducing congestion in urban areas due to motorized transport, where riders are to pay a small fee to ride a bike from one point to another, and then leave the bike at the ride-share station. Such schemes were promoted for preserving environment as well as the opportunity to get healthy exercise. Such systems are already in operation in several major metropolitan cities including in India, which are expected to become more common over the coming years. Such bicycle-ride-sharing stations in Melbourne and India are shown in **Fig. 18** and **Fig. 19** respectively.

In this context, megacities across the world have also seen a steady growth of micromobility

Fig. 18 : Bicycle-sharing in Melbourne, Australia

Fig. 19 : Bike-sharing in Bhopal, India

solutions like e-scooters, electric bikes, electric skates, etc. offering viable solutions in alleviating traffic congestion. The main concerns with micromobility in particular are safety related and whether the current infrastructure can support the massive influx of these vehicles, and for now the cities in India are not fit to allow growth of micromobility. A street with dominance of micromobility choices is seen in **Fig. 20**.

Cars will still be on our roads, however the energy that powers them and the way in which they are bought, leased or rented and operated will certainly change. The above examples of future transport systems are just some of the innovations on the horizon for the future of urban transport in India.

Sustainable Transport in Future

Sustainable transport and mobility are fundamental to progress in realizing the promise of the 2030 agenda for Sustainable Development

Fig. 20 : Urban street with micromobility modes

Goals (SDGs) and in achieving these 17 goals. As members of the international community, India has shared responsibility to shape the transport agenda to meet these goals. Sustainability in intercity and city transport means for reducing its carbon footprint with smart technologies and integration of different modes of transport for maximizing the output. Thus, innovation only is relevant and pertinent for timely intervention and directing transport policy for sustainable future.

E-Vehicles

The National Electric Mobility Mission Plan (NEMMP) of the government targeted sales of 6-7 million electric and hybrid vehicles to be sold in India by 2020. Under this plan, the government seeks to facilitate electric vehicles to be the first choice of buyers through demand interventions like reducing GST rates with no cess, tax and developing charging facilities. Another scheme Faster Adoption and Manufacturing of Electric/ Hybrid (FAME) targets to electrify public transport and shared transport (like 3-wheelers and 4-wheelers registered as commercial vehicles). It has been estimated that by 2030, 56% of the vehicles produced worldwide would use combustion engines, 35% would use hybrid technologies, and 9% would use electric power. Therefore, a large proportion (nearly half) of all smaller vehicles would not use a combustion engine and thus reducing emission of Green House Gases (GHG) to a significant level.

100% battery driven electrical vehicles are the ultimate goal of the vehicle alternative powertrain development over a period of next 20 years. In

India in particular, dual fuel vehicles (running on petrol / diesel and CNG) have gained popularity. Among electric vehicles, brands like Mahindra, Toyota, and BMW have created a market presence, and government proposes to incentivize adoption of green vehicles and facilitate domestic manufacturing capability. Moreover, the recent move of government to prioritize electric mobility is giving the market its long-awaited push. Thus the focus on electrification as the primary technology pathway to achieve this transformation to clean energy presents India with a powerful opportunity to emerge as a leader.

Electric Vehicles (EVs) for roads include a large range of vehicles from electric two- wheelers, three-wheelers (rickshaws), electric cars, electric buses to electric trucks. Especially buses and trucks are going to play a vital role in intercity travel which will lead to sustainability. At present there are more than 0.5 million electric vehicles on Indian roads, and majority of them are two-wheelers. Though the electric vehicle industry in India is seeing rapid growth, it is happening in the two-wheeler, three-wheeler and four-wheeler industries and in case of commercial segment, it is limited to Light Commercial Vehicle only. The first intercity electric bus service between Mumbai and Pune was launched this year with a range of 300 kilometre on a single charge and would be operated twice daily between the two cities. It is shown in **Fig. 21**.

The advantages of such electric vehicles would be in terms of superior mileage (40% lesser energy requirements) and reduced maintenance. With 1/5th moving parts, no engine, no ignition components, no exhaust, reduced wear and tear of brakes, these vehicles lead to 40% lesser cost of maintenance.

E-Highways

The concept of e-highway is not new, with a number of other countries already testing this idea by building an overhead contact line for electrified freight transport on expressways generally. As part of strategy to boost electric mobility in the country, India is also planning to trial an electric highway (e-highway) on the proposed Delhi-Mumbai expressway within the next three years to boost electric mobility in the country. Trucks of 80t will be deployed and these will have electric cable to draw power from the overhead cable network. There will be two tracks and trucks with containers can run at 100 km/h. The trucks will run on electricity for 20 km and the battery will get charged to run on stretches where there is no overhead wire. Again, after some kilometres, these can tap the overhead wire and simultaneously get charged again while running. Initially, a 10 km pilot e-highway will be built with overhead electric lines to power the engines of trucks and buses. The pilot will be carried out by the Ministry of Road Transport and Highways in collaboration with the Department of Heavy Industries. The required infrastructure for e-highway is similar to electrified railway track and it is estimated that 10 km section of e-highway will need an investment of approximately Rs. 2 billion. The representative e-highway is shown in **Fig. 22**.

Integrated Multi-Modal Transport System

Intercity transport planning cannot be implemented in piecemeal manner for individual

Fig. 21 : Electric bus for intercity travel

Fig. 22 : E-Highway for intercity trucks and buses

modes (air, road and rail). An integrated national intercity transport plan looking at all modes comprehensively will help understand demand and ridership for these modes and help prioritize investments. Regional rail and bus services should act as feeder systems for HSR and Hyperloop corridors to increase the catchment of these fast infrastructure corridors, and benefit a large regional population. High speed systems will complement air modes, especially at hub airports. Planning high-speed system infrastructure and managing time schedules strategically can facilitate better connectivity to airports with seamless inter-city and international travel opportunities. Leveraging the capacity and operating economies of multiple modes of transport - road, rail, coastal and inland waterways, small regional airports, ropeways, etc. need to be considered to transform countrywide transport system in India.

Another multi-modal transport concept for sustainability is Roll-On Roll-Off (RO-RO) services operated by Konkan Railway, where the trucks are taken on train for the part of the total journey to be rolled out at the other end of train travel, which is highly economic, fast and safe. The actual operation is shown in **Fig. 23**.

Government of India promoting Connect Bharat with one clear imperative for this transformed mobility paradigm is to build Safe, Adequate and Holistic Infrastructure (SAHI) for all citizens, including women, elderly and disabled. Also, the infrastructure network needs to solve for all types of connectivity - urban-to-urban, urban-to-rural and rural-to-rural. Multiple current schemes such as Pradhan Mantri Gram Sadak Yojana (PMGSY), Pradhan Mantri Jal Marg Yojana (PMJMY), High Speed Rail/MagLev Plan and UDAN (Ude Desh ka Aam Naagrik), etc should be implemented in a coordinated manner to achieve the most balanced distribution of demand for a sustainable future. Intelligent transport system infrastructures with interoperable tolling/pricing systems along with all other smart technologies are likely to meet the need of expected passenger traffic demand likely to grow at the phenomenal rate of about 15% per annum with an integrated multi-modal transport system for seamless travel experience.

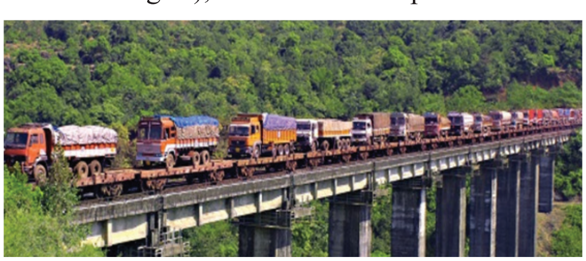

Fig. 23 : RO-RO operation of Konkan railway

CONCLUSIONS

Historically road transportation was developed to support non-motorized forms of transportation (walking, domestic animals and cycling at the end of the 19th century), and it is the motorization that has shaped the most of its developments since the beginning of the 20th century. However, a new paradigm shift is emerging, which is likely to trigger the most important technological transition in transportation since the introduction of the automobile. This also will change the ownership structure of vehicles that have been dominantly private, towards a leasing system, i.e. a concept of on-demand service.

The engineering innovations in future is surely going to shape the transportation systems in the world in a smarter way, and India with its massive population base will necessarily siege the opportunity to leapfrog to transform its transport system to be more efficient and productive. Desire for movement has driven the humanity with the evolution to the present day systems, but the variety of demands with speed and flexibility in means of transport is going to transform the future of transportation systems, both in urban and inter-urban travel. In an ideal scenario, all forms of transport including the 'fifth mode', the hyperloop, will be faster, more efficient, and seamlessly integrated, both physically and digitally. There are also expectations that it will be increasingly customised and the degree of autonomy will also decide the way people will travel in the future.

Future transport systems will need intelligent transport system designed with smart physical infrastructure for connected vehicle operations. A network of connected and identifiable devices is commonly labelled as the Internet of Things (IoT) is taking shape and these devices can be embedded in transportation modes, such that vehicles and containers, which then can be more effectively managed and routed. AI and IOT applied at appropriate level to provide an integrated multi-modal system is likely to satisfy all types of future demands. In this process, an added dimension shall be the use of other than fossil fuel, and the most prominent one is the electricity. In addition to a lower environmental footprint, electric vehicles are mechanically less complex with fewer moving parts and hence a longer life cycle. According to policy of Delhi government, all delivery service providers shall be expected to convert 50 per cent of their fleet operating in Delhi to electric by March 2023, and 100 per cent by March 2025, which will have significant impact on reduction of pollution level. But, expansion of electric vehicle fleet must include strategies for the supply of electrical power to these vehicles with required charging stations. It may be noted that electric vehicles can be charged by wireless power transfer technologies simply by being in proximity to a recharge node or they could even be recharged as they drive around equipped roads and surplus electricity could be distributed in the grids for use during periods of peak demand.

A fundamental component of future transport systems, freight and passengers alike, is that they must provide increased flexibility and adaptability to changing market circumstances (origins, destinations, costs, speeds, etc.). An important challenge lies on the balance between market forces and public policy, as both have a role to play in the transition. Economic development and globalization have been important factors behind the surge in the demand for mobility. Governments have consistently been poor managers and also have the tendency of preventing technological innovations in the name of regulation. Recent history indicates that it was when deregulation took place that the most significant changes and innovations resulted in transportation, and therefore, it is very likely that future transportation systems may be the outcome of private initiatives, or public-private partnership schemes. Also, the economic history has shown that market forces would always try to find and adopt the most efficient form of transportation available. The changing of obsolete transport technologies to more efficient and cost effective ones would then reflect the level of abundance of energy, resources, space, and time.

The transportation systems have been the barometer of economic, social and commercial progress in the societies and transformed the entire world, as required, into a connected one. It is important that we make transport systems more resilient and at the same time more sustainable and inclusive. Moreover, all the innovative prowess transport can muster is very essential at this time to tackle the challenge facing the sector after stalling transport activities and the economies that depend on it due to the global pandemic. The vital importance of this ability to innovate is surely one of the major lessons for transport from the pandemic by which everything is likely to change for a sustainable future. India's multi-prong approach to transform its transport systems in the country through very extensive programmes taken up for rural roads to expressways to high-speed rail and hyperloop, etc along with a wide variety of urban transport modes supported by sustainable transport policies is likely to realize an integrated multi-modal mobility scenario in the coming future.

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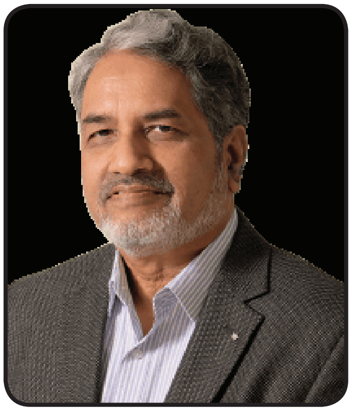

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Future Engineering Education: Conventional and Online

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INTRODUCTION

Engineering is application of science to improve quality of human life. It is a process of making use of scientific principles to make human life more comfortable and enjoyable. The process is highly creative and innovative as the same scientific principle can be used to achieve variety of functions, sometimes even diametrically opposite. Take the example of electricity. Electricity can be used for generating heat as well as for cooling. Any innovative processes that improves the benefit-to-cost ratio for humans can be put into the domain of engineering. The benefit could be in terms of comfort, safety, reduction in boredom, efficiency of work, high productivity, reduction is risk etc., whereas the cost could be in terms of money, physical labor, natural resources, etc. Engineers use their innovative ideas to design new processes and products that maximize the benefit-to-cost-ratio. However, while achieving this, the engineers have to function within various constraints which are not only technical but could be social, financial, political, ethical, etc. A good engineer therefore has to be aware of various aspects of society in addition to having robust and contemporary technical knowledge and innovative ideas.

There are few things that are noteworthy about engineering. Firstly, the engineering addresses the contemporary needs of the society. Secondly, it is dependent upon the scientific knowledge that exists at that point of time. A product or process may appear superb at a given point in time but may appear useless at later time. One of the classic example is the vacuum tubes. The vacuum tubes were the most powerful devices that gave birth to electronics which subsequently gave birth to many life changing devices and systems. However, once the semiconductor devices were invented, within a span of a decade, the vacuum tubes vanished behind the scene. Same has practically happened to mainframe computers once the personal computers were invented. Thirdly, the engineering and society adapt to each other. So, engineering is not just a technical idea, it is an innovative technical idea launched at right time. Timing is very important for an engineering outcome to succeed. Many a times a great idea may die its pre-mature death because the society may not be ready to accept that idea. One may be surprised to know that when the arc lamps were invented, there was substantial opposition from the environmentalists. On the other hand, a radically new idea of internet was readily accepted by the society. The engineering therefore depends upon the societal needs, and the societal mindset depends to some extent upon the state of engineering and technological development at that time. The problem seems entangled and it is impossible, at best difficult, to predict the path of engineering in far future. However, some short and medium-term projections of engineering can be made with some accuracy. It is possible that every prediction may not come true but a prediction over a decade or so may not be too much off the track.

Here we try to make an attempt to assess the direction of engineering and engineering education over the next decade or so. It is clear that in addition to technical competence, an engineer has to be trained in many non-engineering aspects so is to keep herself productive over the entire professional life.

HISTORY OF ENGINEERING EDUCATION

Engineering goes as back as the ancient civilization. However, that time engineering essentially meant civil and metallurgical engineering. Wonderful architectural marvels have been created on entire time line of the known history. Similarly, artifacts made of iron, copper, brass (which is an alloy), zinc, gold, silver etc. have been in use since ancient times. The other engineering disciplines essentially evolved just about two centuries back during scientific and industrial revolution. The steam and water replaced the human and animal muscle power making energy conversion a major milestone in the history of mankind. Later, with the arrival of electricity, many new machines were created which led to mechanization of many processes and mass production.

The engineering education per say was non-existent even during that time. The engineering was essentially a creative process through trial and error. Most of the engineering work used to be experimental realization of principles of basic sciences. However, in eighteenth and nineteenth century, engineering adopted more systematic and scientific approach to practical problems. Calculus and Newton's laws of motion became the basis of designing and developing machines. Engineering became a profession, workshops became laboratories, tinkering became industrial research and individual innovations became team innovations, and formal engineering schools were established. Due to sound mathematical foundation, the systems became optimal and efficiency increased. The engineers primarily became the designers and conceptualizers and the developmental work was shifted to technicians.

The most transformative phase of human growth has been the information age. During this period, due to availability of information through journal publications, etc., the science and engineering became collaborative leading to its exponential growth. In twentieth century, the engineering research (applied research) outgrew the natural science research. Engineering got a new thrust by technologies like aerospace, computer, nuclear, telecommunications, semiconductor, materials etc. Today's engineering essentially is an extension of this phase.

Due to collaborative research at global level, each branch of engineering grew exponentially. The consequence of this explosion of knowledge in every discipline of engineering was that the engineering became more and more specialized and compartmentalized. Up to nineteen eighties, the engineering programs in India were of five years duration and the first two years were devoted to general engineering covering basics of all branches of engineering and science. However, after the duration of the engineering degree program was reduced to four years, the engineering got more confined to a particular specialization. For example, today an electrical engineering student will know very little about civil or mechanical engineering and vice versa. This change started creating lopsided engineers with less or no holistic vision.

As per one of the studies of IEEE, in last 100 years, the engineering education changed about five times. The first shift was during 1935-1965, when the emphasis was shifted from pure hands-on to science and analytical approach. Since the computing power was limited at that time, the thrust was on creating analytical engineering models which sometimes were less accurate but more mathematically elegant. The second shift came in eighties when the outcome-based education and accreditation was introduced in technical education. The engineering curricula were changed to specifically bring out the capabilities of graduating engineers. It also provided adequate emphasis on holistic development of engineering graduates including professional ethics and best practices. The third shift came toward the latter half of the last century, where the design thinking got introduced in the curriculum. Capstone projects became a common practice in engineering programs. The design projects also got introduced right from the first year of the programs. The role of computer increased in every branch of engineering by manifold. Computer programming became a compulsory course for all engineering students. More sophisticated and accurate models of devices and systems were studied and simulated using computational tools.

The next major shift took place at the beginning of this century with deployment of information and communication technology (ICT) in engineering education. The engineering education started using electronic platforms for teaching and dissemination of knowledge. Although the signs of this mode of content delivery became visible in eighties through TV and audio tapes etc., the major transformation took place after the arrival of internet technology. This was a disruptive technology in the education space. The teaching-learning paradigm was changed from synchronous to asynchronous. This is the technology that appears to be the future of the education. We will discuss some of the aspects of this mode of education in detail in the subsequent section.

PRESENT ENGINEERING EDUCATION IN INDIA

In last three decades the base of engineering education has expanded almost by an order of magnitude. A large number of engineering institutions were established in a short span of time. Engineering became the first choice for graduating students. While there were many new Govt. institutions, the major expansion took place in private domain. However, due to excess supply of engineering seats, the quality of engineering graduates dropped considerably. Many non-deserving students got admitted into engineering programs because not filling the seats due to lack of merit was not acceptable to private engineering institutions for financial reasons. Even with this, today almost 40% seats are vacant in engineering institution on average. This impacted the quality of engineering education in two ways. One, it reduced revenue from fees and financial sustenance of engineering institutions became difficult. Faculty were hired at reduced salaries and the quality of faculty dropped due to non-attractive perks. Second, it reduced the laboratories and hands-on experience which is the core of engineering. The engineering education became more simulation and modelling based with very little exposure to real life problems. Further, most of the institutions shied away from setting cost intensive branches of engineering. Today more than 80% of the engineering institutions host only less cost intensive branches of engineering like, computer and electronics engineering and their offshoots.

In last 100 years there is tremendous growth in every branch of engineering. As a result, the engineering education became more and more specialized and compartmentalized. After reduction of the duration of the degree program, the specialized courses started right from the second year of the program. Today, only first year curriculum is broad based covering basic sciences and humanities courses, but in some cases the specialized courses get introduced even in the first year. The compartmentalization of engineering education did not remain confined within the domain of engineering, the engineering education as a whole got disconnected from the other disciplines of science and arts. Many States established the technical universities and all the engineering institutions within the State got affiliated to the technical universities. This development in some sense was detrimental to the holistic development of engineering graduates. It is important to realize that engineering addresses the needs of the society and therefore an engineer should not understand only technology but its social implications as well. Some corrective measures however have now been proposed in the National Education Policy (NEP) 2020.

One good thing however has happened in last two decades and that is, the importance of biology has been recognized and engineering students are exposed to basics of biotechnology. A Bachelor's degree in biotechnology is currently offered in many engineering institutions in India. It is expected that bio-inspired engineering will be the way forward to make energy efficient and sustainable systems in future.

In last few decades, the computer science grew disproportionately primarily due to unprecedented growth in the software industry. The software industry provided a huge and far more lucrative job market to graduating engineers. Since the software industry is skill based, and the required skills can be acquired in a relatively short span of time, even non-computer engineers preferred jobs in software industry. As a result, the other branches of engineering got a back seat. The manufacturing industry suffered due to inadequate trained manpower in core engineering sector. The manufacturing industries became less competitive and industries became service oriented. In is clear that with time, the size of software industry is going grow by manifold and therefore many more computer/software engineers will be needed in future compared to any other type of engineers.

FUTURE ENGINEERING FIELDS

Since engineering addresses contemporary issues of the world, the future engineering will depend upon the way the future world evolves. It is interesting to note that future world is going to be dominated by technology and therefore the evolution of future world will be decided by the technological development. This is a complex entangled problem and therefore prediction of engineering and technology over long period is very difficult. However, one may realize that today our society lives in two very different worlds simultaneously. One world is the physical world in which basic human needs are defined. This world depends on the natural resources and local geographical, societal conditions etc. The other world is the cyber world which is global in nature. While the evolution of the cyber world is impossible to predict beyond few years, the evolution and needs of the physical world can be extrapolated with reasonable accuracy for next few decades.

The studies by international organizations predict that in next few decades, the world's population will rise by 50%, the energy requirement will rise by 100%, electricity requirement will rise by 300%, and food requirement will rise by 200%. At the same time the conventional natural resources will be down by 60-80%. The population that will be stressed even for an essential life element like water, will be up by 200%. The major impact of this will be felt in the developing countries including India. In short, to sustain the modern life style for the entire population of the world, one would need resources equivalent to four earths. The aspiration of modern life style with equitable distribution of natural resources further gets emphasized by the interconnectivity of the world. The solution to the problem needs to be found by the engineers and technologists. The future engineers therefore need to be aware of the broader picture of the world.

Green engineering is the only way to move forward in a sustainable way. This demands that the environmental aspect of engineering processes and technologies are to be integrated in the engineering education. At present an environmental engineering course is mandated in all educational programs including the engineering education. However, the green engineering goes far beyond this. It asserts minimization of the wastage of natural resources and also includes the life cycle impact of a process or a product on the environment. The green engineering insists on developing engineering solutions taking cognizance of local geography, climate and culture. It therefore nurtures the natural diversity of regions, and cultures. Active engagement of local communities and stakeholders in finding engineering solutions to the local problems will be the need of future engineering.

The National Science Foundation, USA has defined engineering grand challenges that need to be addressed in coming decades. Some of them are, (i) making solar energy economical (ii) provide energy from fusion (iii) Manage nitrogen cycle (iv) provide access to clean water (v) restore and improve urban infrastructure (vi) advance healthcare informatics (vii) engineer better medicine (viii) reverse engineer the brain (ix) prevent nuclear terror (x) secure cyber space (xi) enhance virtual reality (xii) advance personalized learning (xiii) engineer the tools for scientific discovery.

The Forbes, AICTE, NASSCOM, and other agencies have identified technologies that would shape the world over next 1-2 decades. These technologies are given in **Table 1**.

A trained leadership, manpower and technical tools need to be developed to embrace these new technology trends. NASSCOM has predicted a huge wave of transformation in digital industry in coming decade. **Table 2** gives the new job roles that would be created in the next decade. Artificial Intelligence alone is going to create 12 new job roles like solution architect, business analyst, data architect, data scientist, AI research scientist, language processing specialist, information security analyst, and DevOps engineer. The new technologies will further find applications in industries like automotive, agriculture, pharmaceutical, banking and retail, manufacturing, healthcare etc.

The main challenge of the future engineers will be to adapt to the rapidly changing world and catastrophically growing new technologies. Technology is progressing at an unprecedented rate and the life span of technology, particularly the ICT, has been reduced to only few years. If the life span of the technology is reduced to less than the duration of the engineering degree programs, the design of engineering curricula will be highly challenging. It therefore appears that we have arrived at a juncture when the engineering education needs a fresh approach. In the following we look into some of the changes that the engineering education is likely to see in coming years.

FUTURE ENGINEERING EDUCATION

Employability including self-employment through entrepreneurship is one of the measures of a successful engineering program. Let us first consider the industrial job market. The entrepreneurship aspect will be discussed subsequently.

Skills for Future Engineers

Today's job market requires about 30% technical skills and 70% soft and professional skills that include professional attitude, for

Table 1 : New technologies for next decade

Artificial intelligence (AI) and machine learning	Voice Interfaces and Chatbots
The Internet of Things (IoT)	Computer vision and face recognition
Wearables and augmented humans	Robots and Cobots
Big Data and augmented analytics	Autonomous Vehicles
Intelligent Spaces and smart places	Machine co-creativity and augmented design
Block chain and Distributed Ledgers	Drones and Unmanned Ariel Vehicles
Cloud and Edge Computing	Cyber Security
Virtual and Augmented Realities	Quantum Computing
Digital Platforms	Robotic process automation
Digital Twins	Mass personalization
Natural Language Processing	Nano Technology and New Materials
5G	3D printing and Additive Manufacturing
Genomics and Gene editing	

Table 2 : New job roles across new technologies

Virtual Reality	16	VFX Artist, Computer vision engineer
Internet of Things	15	Wireless network specialist, Embedded system Programmer
Big data Analytics	8	Data Scientist, Data architect
Artificial Intelligence	12	AI research scientist, Language processing specialist
Robot Process Automation	6	RPA Developer, Development engineer
3D Printing	7	3D modelling engineer, 3D designer
Cloud Computing	3	Cloud architect, Migration engineer
Social and Mobile	6	Android app developer, Digital Marketing

an engineer to succeed. The technical skills consist of rigorous domain knowledge, sound fundamentals, knowledge of programming and computational tools etc. Whereas the soft and professional skills consist of critical thinking, problem formulation and solving capability, interdisciplinary and system thinking, imagination and creativity, managerial skills, leadership skills, communication and collaboration, digital literacy etc. The professional attitude consists of global mindset, quality culture, integrity, ethics, and lifelong learning. According to the World Economic Forum report (Ref. AICTE report), the estimates of the skills required over next decades will be as given in **Table 3**.

All these attributes have been well captured by the accreditation process set up by the National Board of Accreditation (NBA). The guidelines laid by the accreditation board will have to be followed not only as a regulatory requirement but as a commitment. Educational institutions will have to be vigilant in tracking the need for the

Table 3 : Skills needed over next decade

Cognitive abilities	15%
System skills	17%
Complex problem solving	36%
Content skills	10%
Process skills	18%
Social skills	10%
Resource management skills	13%
Technical skills	12%
Physical abilities	4%

new skills. The curricula will have to be updated frequently to maintain pace with the industrial need. This cannot be achieved without a strong Academia-Industry partnership. Industry-academia relationship has to be strengthened to make future engineers more employable.

Academia-Industry Partnership; A Win-win Proposal

The industry-academia partnership has grown substantially over last two decades. However, it is far below the desired level. Generally, people look at this partnership for internship and placement opportunities for students and may be for some sponsored projects. However, the industry can play a far more active role in engineering education at multiple levels.

First and foremost, is the industrial inputs for designing the curricula that is futuristic. The industries are aware of the technology trends and their potential for commercialization. The presence of industry professionals on Governing Boards and Boards of Studies should become mandatory for every engineering institution. Industry professionals also should participate in accreditation process which is so important for creating quality culture at academic institutions.

Secondly, the industry professional will have to be involved in teaching as visiting faculty. This will expose the students to the contemporary developments in the industry. Students then can orient themselves to make them suitable for industrial needs and will make them more employable.

Thirdly, the industrial internship should become more vibrant and productive. Students should spend six to eight months in industry to make the internship more productive.

Fourthly, there should be provision for faculty to spend their vacations and sabbaticals at the industries. This will affect the engineering education in two ways; the faculty will be exposed to the current industrial activities and needs, and industries will be able to make use of the academic expertise in solving their problems. Involvement of the industry professionals in academia and academic faculty in industry will build an environment of trust between the two which will encourage industrial research to be carried out in engineering institutions. It will be a win-win situation for both academia and industry to make engineering institutions the R and D houses of industry.

The recent AICTE-CII survey conducted on 9581 institutions on industry-academia partnership reveals that only about 78% of the engineering institutions have some kind of linkage with the industry, the remaining has no linkage at all. However, among the institutions that have industry linkages, the participation of private organizations is very low. In terms of the funds received for setting up cells or labs, about 5% institutions received about Rs 5 Lac, whereas the institutes that received industrial grant of more than Rs 1 Cr, are less than 0.5%. These numbers are not very encouraging. Industrial investment in academic institutions will have to be increased by manifold in the coming decade. Industrial funding base should be expanded to multiple activities like Chair professorships and endowments, PhD fellowships, remuneration for faculty spending sabbaticals in industry, establishing research centers at academic institutions, sponsored projects, support for filing patents for the work done jointly by industry and academia, and so on.

When it comes to sponsored industrial projects, generally, the industries do not expect much in return from the academic institutions. It is treated more or less like a CSR activity. As a result, there is not much accountability in the sponsored project. This model needs a change. Instead of project sponsorship, there is a need to develop R&D partnership. In this model the industry and academic institutions have to work jointly on an industrial problem. It is important to realize that industry and academia have complementary strengths. Free thinking and up to date domain knowledge is the strength of academia and the applicability, market assessment, knowledge of societal needs is the strength of industry. Academia also has a unique character and that is, it has free flow of young minds and there is no stagnation of ideas. University of Pune has been successful with this model of 'R&D for industry by industry' where the industry-oriented PhD program is fully supported for carrying out research that is used by the sponsoring industry.

Innovation and Entrepreneurship

In the knowledge driven society, innovation is the key to success. The future engineering education should facilitate and nurture innovative and entrepreneurial mindset. However, this is easier said than done. The curricula should create provisions for nurturing unconventional thinking. For this to happen, the curricula should be flexible and less loaded. Also, the current approach of mass education should become personalized. Evaluation mechanism should change substantially to mentor the unconventional thinkers who do not fit into a straight jacketed education system. For an innovation to be more socially relevant, integration of engineering, information science and life science, and social science will go a long way. Curricula also should encourage students to try unexplored areas without fearing failure. There are ample examples in the scientific history of using failures as stepping stones to achieve something far bigger. Industrial mentorship for budding entrepreneurs will have to be established at the engineering institutions to encourage innovative and entrepreneurial mindset among graduating engineers.

Impact of NEP-2020 on Engineering Education

After 34 years, the National Education Policy (NEP) 2020 has been approved by the Government of India. The policy has recommended many reforms in higher education systems so that the education becomes forward looking and relevant. The NEP 2020 is going to impact the fabric of engineering education also.

The NEP-2020 has advocated multidisciplinary and flexible education system. Realizing that most of the engineering problems span across many disciplines, the compartmentalization of the engineering fields will have to become weak. The boundaries between different departments will have to get more diffused. Engineering curricula should become flexible so that students can decide their basket of courses and self-define their expertise. The traditional departments may not sustain and their restructuring to reflect the new engineering trends is imminent. NEP-2020 further facilitates multiple specializations in diverse areas of engineering and other subjects. Design thinking, integration of knowledge, and exposure to societal problems have been emphasized in the education policy. There is a strong emphasis on vocational and hands-on education in NEP-2020. However, that will need huge experimental facilities that are cost intensive. Academic clusters around industries, as proposed in the AICTE report, will be the need of the future.

NEP-2020 amply emphasizes the holistic development of students including the technical students. The curricula should inculcate ethical values, integrity, and quality consciousness among the engineering graduates. A sufficient liberal arts component will have to be introduced in the engineering curricula for making the future engineers well informed about culture, values and societal needs.

Online Mode of Engineering Education

It is envisioned that the future education will be heavily dominated by the use of technology. In fact, the use of ICT in education started as long back as 2000. However, that time the objective was very different. As mentioned above, in nineties, there was explosion of engineering institutions in the country and there was acute shortage of qualified engineering faculty. To fill the faculty gap, the MHRD initiated the National Program for Technology Enhanced Learning (NPTEL). Under this program the subject experts from IITs were invited to develop full courses in video and web formats to cover the entire curriculum for five major engineering disciplines namely, Computer Science and engineering, Electronics and communication engineering, mechanical engineering, electrical engineering and civil engineering. Later, many more disciplines were added. Also, around 2010, a virtual lab project was initiated by MHRD. These teaching-learning resources were made available to all the engineering institutions free of cost. Of course, the evaluation/examination platform was not developed under this initiative and that aspect was left to the individual institutions. Later, even proctored examination and certification component was added to NPTEL under the broader digital e-learning platform, SWAYAM.

Currently, the online courses are only optional and generally not integrated in the curriculum. Although, AICTE has permitted up to 20% of the curriculum to be in the form of e-courses from SWAYAM, due to many implementation issues, the SWAYAM courses still have not achieved the utility as expected.

During the lock down due to COVID-19 pandemic, the online mode of education was proved to be a great boon. Since the conduct of face to face classes became prohibitive due to social distancing restrictions, the regular classes had to be shifted to electronic mode. The classes became countrywide though they remained synchronous in time. Most of the educational program continued without much disruption during the lock down period.

The online education was envisioned even before the pandemic, but since there was no compelling reason to adopt it, it was at a very low level. The pandemic forced the usage of online education and also gave confidence to the academic community and students that the regular classes could be conducted in online mode effectively. It appears that online education is going to be the future trend!

Indeed, online education has many advantages. Online education is learner-centric and provides a platform for lifelong learning. In the future world, where technology is going to change rapidly, online education can keep engineering professionals up to date through self-learning. Online education also will provide exposure to global knowledge to people of every strata of society. Online education therefore is a great equalizing factor. Further, it can expand the reach of education to the remotest corner of the country. It also provides flexibility in selecting courses of one's choice and designing almost tailor-made programs.

While these aspects appear to make online education as the future mode classroom teaching, it has certain limitations. One needs to be cautioned that every subject may not be suited for online mode of teaching. Courses, especially the ones that have experimental or logical content, are not very much suited for online classes. In a curriculum, the courses that suit the online mode of teaching, are to be judiciously chosen. It therefore appears that future mode of teaching will be blended in nature.

One of the main challenge of the online education is the robust evaluation mechanism. Experience shows that the un-proctored evaluation in online mode is not dependable as it demands high integrity and discipline from the learners. Online evaluation also puts restrictions on the type of questions that can be asked in the examination. A lot more work is needed in this direction to make online evaluation reliable.

In addition to the limitations of online education from content delivery and evaluation view point, there are other challenges like availability and affordability of high speed internet connectivity. If an affordable, high-speed data connection is not available, the live online classes will not be effective. The students who do not have high-speed data connection then will be deprived of quality education and there will be social digital divide. Some of these challenges came to light during the COVID pandemic. Another aspect of online education that has not received enough attention, is the psychological aspect. It has been observed that long exposure to the computer screens and no physical interaction with peers, creates fatigue. Psychologists fear that it may lead to depression.

The above analysis suggests that future engineering education should not be completely changed to online even if the technology permits. For creating professionals with right ethical values and healthy mind, a correct blend of online and face-to-face education is envisaged. May be 30-40% delivery in online mode will be a healthy norm for future engineering education.

WAY FORWARD

In next few decades the engineering education is expected to undergo a significant change. New technologies like AI, data Science, robotics, bio-inspired engineering etc., will become the major branches of engineering. The concept of 'honors program' for those engineering students who wish to study at deeper level, will be desirable feature of engineering education. The conventional engineering disciplines will diffuse and evolve into new disciplines. A more multi-disciplinary curriculum that is flexible and dynamic, will be the need the of day. Lifelong self-leaning will become a norm and engineers will have to keep learning new technologies and acquiring new skills to remain relevant to industry. For that to happen the technology enabled learning will become prevalent. Through a strong industry-academia partnership, globally competitive but locally relevant engineers with high ethical values will have to be created. Industry professionals will have to play an active role in designing forward looking curricula and should participate in imparting practical knowledge to the students. To carry out cutting edge industry-oriented research, academic institutions should become the R&D houses of industry. The new curricula should provide ample soft skills like team work, handling failures and entrepreneurial mindset. Engineering programs that are less loaded and less rigid can create non-conventional thinkers and innovator. Sustainability issues will have to be given ample emphasis in engineering curricula. Further, as emphasized by the NEP-2020, liberal arts education should be integrated in technical education sooner than later to create engineers who are socially aware and will work towards developing technology for humanity as a whole. A holistically developed future engineer will then play a major role in shaping the policies that reflect the ethos and aspirations of a modern world.

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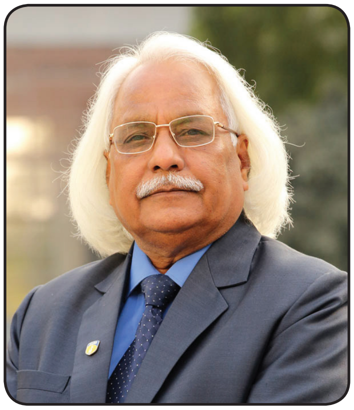

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Professor Pritam B Sharma graduated in Mechanical Engineering from Samrat Ashok Technological Institute of Vikram University in 1969. He was sent by Govt. of India as a National Scholar for higher studies abroad and he obtained his Post Graduate Degree in Mechanical Engineering from University of Birmingham (UK) in 1974 and received the Post Graduate Prize for being the topper of the Engineering Faculty of University of Birmingham. He later received his Doctorate Degree in Mechanical Engineering from the University of Birmingham (UK) in 1978. Prof Sharma is a man of vision and firm commitment and resolve to nurture academic and professional excellence in originations and Institutions to which he has associated himself during his 37 years long professional career.

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ABSTRACT

With the advent of the new age of innovation, massive disruption of the existing systems is already becoming a reality. However, massive disruption is always associated with futuristic possibilities of accelerated growth and development as the ingenuity of man finds immense opportunities to create new waves of development and growth powered by new and emerging technologies. AI, Machine Learning and increasing automation are bound to create abundance of opportunities for growth and advancement of humankind and that of creative economies. In the present paper the authors have attempted to describe the role of AI and automation as drivers of future.

INTRODUCTION

Science and technology have been the prime movers of societal development and industrial growth ever since the advent of man on planet earth. For the early man,the glaring galaxies in the sky and the beauties of nature attracted his attention to discover the essence of nature in the form of colours, fruits, vegetables, herbs and spices which made a big sense to explore nature and the surroundings. Further, the ingenuity of man continued to translate its scientific quest into usable products and knowhow to enable early man to lead a healthy life in harmony with nature. We find great advancement of science and technology in the text of the Vedas, the ancient most written records of enriched wisdom of man composed in antiquity but systematically written down some 5000 years ago, coinciding with the Mahabharata times. No wonder that the earliest colour dye is christened by its European inventors in the modern scientific era as Indigo. The discovery of cotton and the capabilities to produce finest of fine textiles provided the mankind a renewed excitement for life and created avenues for trade and business for our Indian community. The metallurgy found its fullest of expression in mining and purification of metals at an early stage of human civilization, it enriched the capabilities of the early man to conquer some of the adversaries of life as also to add a renewed charm for ornaments and jewellery.

In India, the river valley civilization provided ample opportunity for man to engage in agriculture, develop settlements akin to modern urban areas equipped with highly innovative technologies for water harvesting, storm water drainage and irrigation systems. It all worked well and great progress was made by humankind for thousands of years till the empowerment of science and technology created near madness to conquer and rule over the territories and kingdoms.

It was however, the steam that provided the wheels of power from the early 20th century in the modern scientific era. We have witnessed great advancement of engineering and technology achieved on the strength of scientific advancements that were translated into new and emerging technologies that promoted new enterprises and new industries and thus new demands and new markets.

HISTORICAL PERSPECTIVE

If we look at the history of science and technology advancements in the modern scientific era, we however find that much of this progress from the early years of modern scientific discoveries was prompted by the military and defence needs. Be it advances in material sciences, communication technologies, space science and technology, nuclear power, space explorations, design engineering and manufacturing technologies, or even scientific tools of decision making based on strong analytical foundation laid by modern computing machines, discovery of radium and uranium that provided a major thrust to nuclear technologies. The defence needs however, did not curtail the use of advanced technologies for civil applications. Take for example the communication technologies or computing machines or even technologies that powered the wheels of power on road, water and in air. Everywhere the growth and development of engineering and technology was primarily for the advancement of human capabilities. All this has changed the thrust of engineering and technology advancement from primarily defence orientation to human centric economic and societal development.

What we find that in areas where science and engineering was pursued in a seamless environment great gains have been witnessed. These include communication technologies, computational techniques, Data Science and Data Analytics, Robotics and Automation, Artificial Intelligence and Virtual Reality, Nano Science and Technology, Medical diagnostics and Bio Medical Engineering, Internet of every Things, IoT and green environment and green energy technologies. It is this seamless environment of science and engineering that holds the key to leapfrog in scientific explorations and technology breakthroughs in the modern age of knowledge and innovations powered by all pervading nature of new and emerging technologies. The future growth will depend upon the ingenuity of man to take strides and cause major breakthroughs as the power of AI and IoT has been now unleashed with its all-pervasive nature and abilities to cause major disruption as also mind boggling creative innovations.

NEW AND EMERGING TECHNOLOGIES

In the more recent past, the successive industrial revolutions have brought in significant development in technical innovation wherein manual tasks have been increasingly replaced by automation leading to minimising the limits of physical capacity. Nanoscience and nanotechnologies, new and smart materials, AI, IoT, Big Data Analytics and ML are the technologies for the future. Artificial Intelligence (AI) coupled with automation has already ushered Industry 4.0 revolution sweeping across all sectors including Healthcare, Education, Green-Power, Transportation and many other fields. The significant research in AI powered by Machine Learning (ML) has even made the use the AI for effective operation in retail, logistics, supply-chain and finance. The increased online activity in the recent times in all sectors of economy has further opened up new avenues for AI and automation based processes and systems. Thanks to Covid-19 for pushing online systems and virtual platforms that can be greatly benefited by increasing use of AI and machine learning technologies.

THE TECHNOLOGIES DRIVING THE FUTURE

Automation, artificial intelligence and other technologies, has opened up new set of possibilities. When done right, automation has been proved to deliver real benefits, including the following: distinctive insights (hundreds of new factors to predict and improve drivers of performance) , faster services (reduction in processing time from days to minutes), increased saving and productivity (labor saving of 20% or more), improved quality (from spot checking to

100% quality control through greater traceability) and increased flexibility and scalability (ability to operate 24X7 as well as scale up or scale down as per demand).

Artificial Intelligence is the transformational technology of the digital age and its practical applications are growing in all sectors of economy at a greater pace. Different applications are being developed using artificial intelligence techniques to solve industrial and business problems. Since AI can lead to higher labour productivity, economic growth, and societal prosperity, therefore, policy makers need to strike a balance between supporting the development of AI technologies and managing the risk from bad actors. On the data issues, government should take initiatives for sharing data, setting common data standards, conducting training programs to nurture AI talent. Given the scale of benefits from AI on business, society and the economy, it is important to remember that the goal should not constrain adoption and application of artificial intelligence rather it should encourage its safe and beneficial use.

ARTIFICIAL INTELLIGENCE

With the intervention of artificial intelligence and machine learning in automation, the daily work activities of almost everyone from miners and landscapers to fashion designers, bankers and even CEOs of companies will change.

In a recent survey conducted by Atlassian (2020), nearly 87% of workers think that AI will change their job by 2020 and 76% believe that at least "some" or "half" of their job could be performed by a robot, algorithm, or AI device. We know that change is inevitable, then why not take an active role in making it successful. Why not take advantage of the opportunities that lies ahead of us.

The following fields are identified as futuristic changes expected for better life of planet and human being:

1. AI in Automotive and Industrial Automation System.
2. Digital Healthcare System with H-IoT (Healthcare Internet of Things)

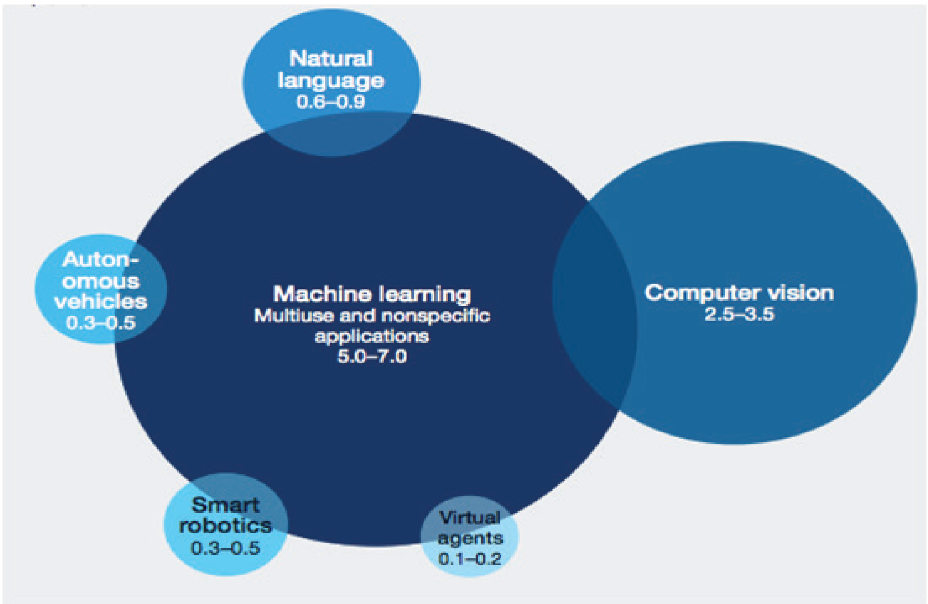

Fig. 1. Boundaries between the different technologies are overlapping but still machine learning received the most investment (Investments are given in $ billion)
Source: Capital IQ; PitchBook; Dealogic; McKinsey Global Institute Analysis

3. AI based Green-Power Sources and Green-Appliances
4. AI in Online Education System

AI in Automotive and Industrial Automation System

The automation in industries are inevitable move to improve the productivity, reduce errors in manufacturing and decrease the time of production. Industrial communication networks have been evolved over the decades which adopt IoT and AI to ensure the collection, processing and transfer of industrial data with appropriate automated decision making capability (Mar Tin Wollsch Laeger et al, 2017). Thus, the current Industry 4.0 is fast opening to next revolution - Industry 5.0 within a short span. The 5-G networks that have already been integrated for faster communication **(Fig. 1)** have been supported by AI to filter the signals intelligently and to create signals that are most relevant to a manufacturing process.

Intensive efforts are being made across the world to harness the benefit of minimized manual intervention in industrial activities through application of AI. Professor Dame Wendy Hall and Jérôme Pesenti (2017) made significant recommendations for further augmentation of application of AI in industries of UK for improvised productivity. The authors recommend the initiation of Government of UK to promote AI among industries through organised funding for research in AI, integration and dissemination of outcome of research to all the industries of UK. The situations in other countries are also similar to that identified and recommended by Dame Wendy Hall and Jérôme Pesenti (2017).

Digital Healthcare System with H-IoT (Healthcare Internet of Things)

Internet of Things (IoT) has deep impact on every system in the world and health care is not an exception. The new terminology Healthcare IoT (H-IoT) has resulted in revolutionary advances

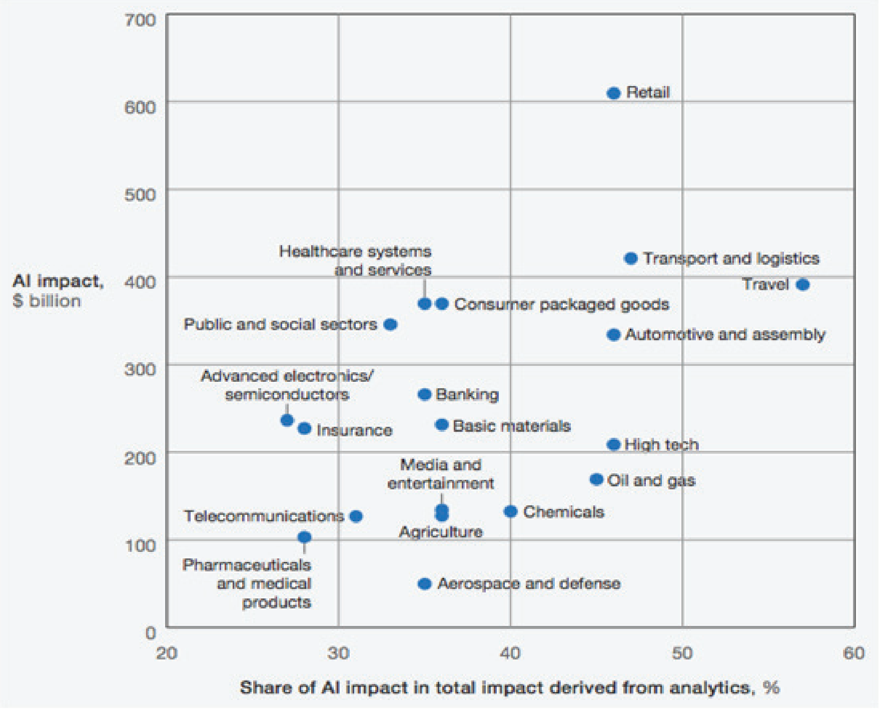

Fig. 2 : Artificial Intelligence has the potential to create value across different sectors
Source: McKinsey Global Institute Analysis

in Medicine 4.0 similar to Industry 4.0. The communication systems between the sensors attached **(Fig. 2)** to a patient and the processors used to process the signals and revolutionary algorithms powered by Artificial Intelligence (AI) system has transformed the H-IoT system at every level (Yazdan Ahmad Qadri et al, 2018). The Internet of Nano-Things (IoNT) along with Tactile Internet (TI) is spearheading the transformation in H-IoT driven by ML, edge computing, and new technologies like SDN blockchains. The techniques of ML are utilised in H-IoT and for maintaining the network towards achieving optimal network and service performance. The future research and development in H-IoT is aptly captured by the researchers (Yazdan Ahmad Qadri et al, 2018) as shown **Fig. 3**.

With the recent pandemic of Covid-19, the world is looking for solutions to overcome the pandemic situation in the shortest possible duration. The invention of vaccine, health care management of affected people are all supported by the power of AI. A good example of use of AI in deriving an effective vaccine is the best example of application of AI in biomedical field.

AI based Green-Power Sources and Green-Appliances

The power harnessing from any source, be it conventional or non-conventional, leaves the carbon footprint. The increases pollution is leading the entire world towards ecological disaster. The digitisation of electric power ecosystem with the implementation of IoT and AI has led to significant improvements in Green-Power harnessing (Guneet Bedi et al). The reduction of energy wastage, improvised efficiency, security against cyber attacks on power systems and sustainability of electric power networks are at the focus with the implementation of AI in power consuming end. Thus AI is being widely applied right from production of electrical energy to the end use in appliances. The IoT sensors connected to production units and appliances at the customer end will be seamless transmission of data and are analysed using AI. The corrective measures are then suggested and taken to make sure that the energy harvesting methodology maintains highest possible efficiency and energy wastage at the utilisation is minimised.

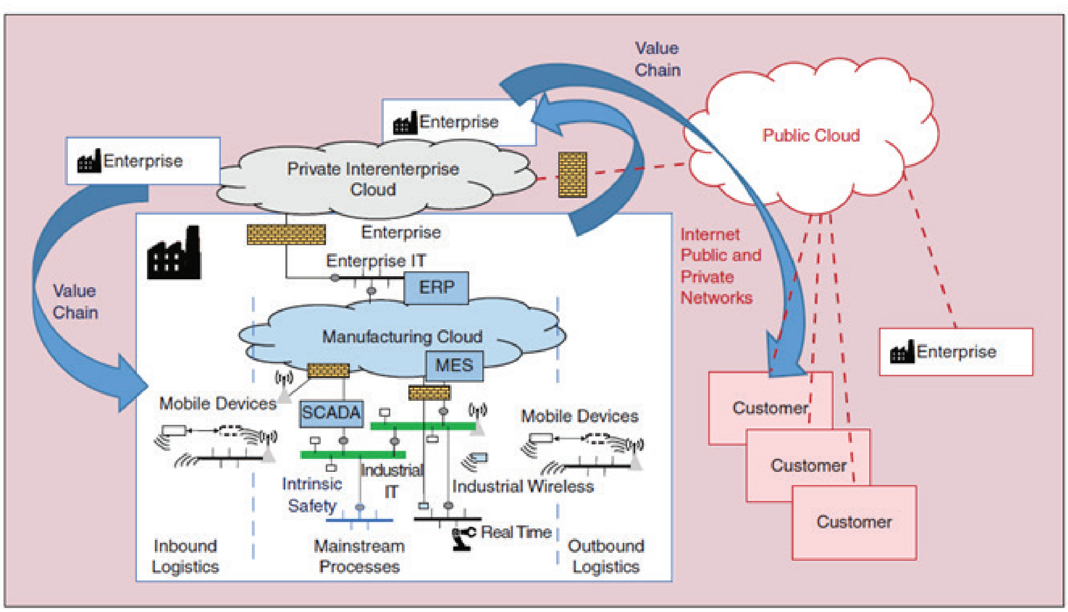

Fig. 3 : The complexity of communication in industrial automation system (Mar Tin WollschLaeger et al, 2017), MES: Manufacturing Execution System, SCADA: Supervisory Control and Data Acquisition, ERP: Enterprise Resource Planning

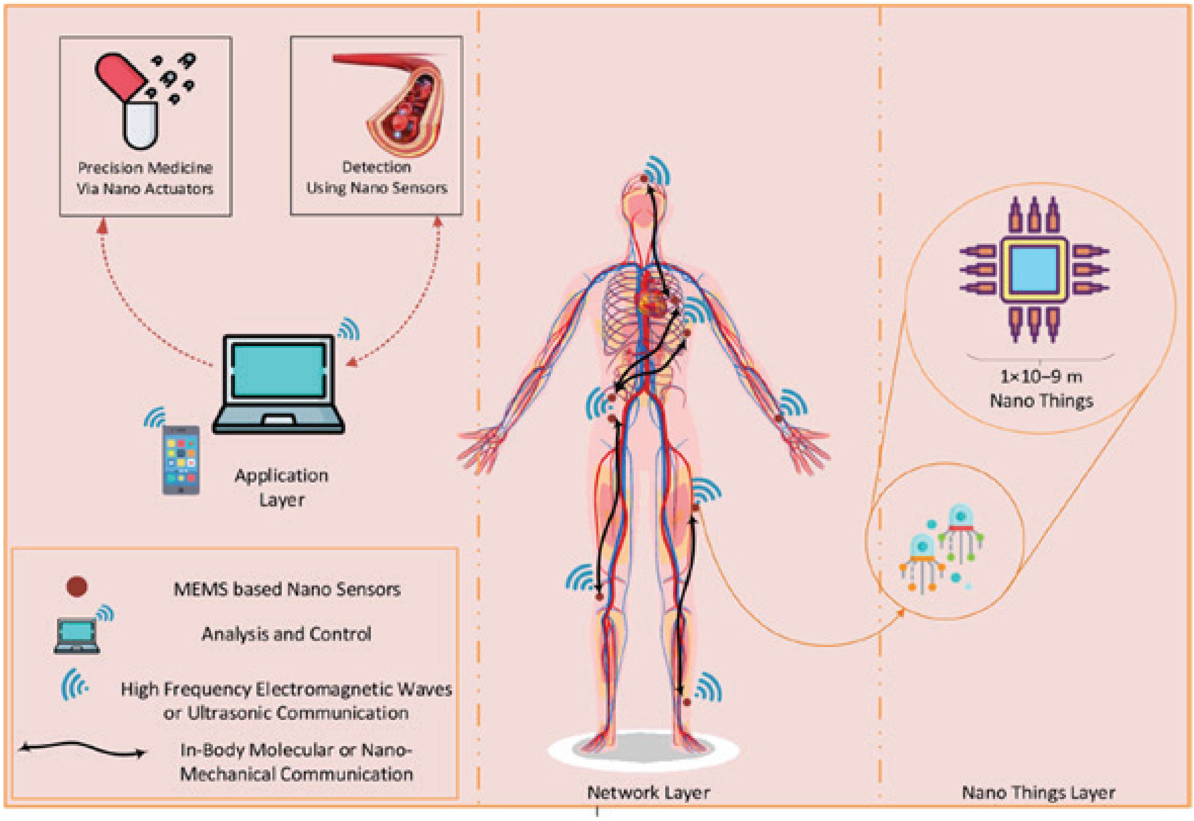

Fig. 4 : A Genetic IoT network (Yazdan Ahmad Qadri et al, 2018)

The major components of electric power industry wherein the transformation using power of AI is being explored is summarised in **Fig. 4**. Towards the self-powered (IoT) by energy harvesting for Green IoT is summarised by Afghan Syeda Adila et al. Since the rechargeable batteries that are used for powering the IoT have lesser life span, new viable solution is suggested. In this system, huge interconnected network of devices are utilised to harvest the ambient energy sources from the surroundings. Smart Grid system is again supported by IoT coupled with AI.

AI in Online Education System

The education system has been experimenting e-learning since two decades. The pandemic of Covid-19 has forced the entire world to embrace e-learning. The definition of e-learning is given by Clark & Mayer, 2002 as "a combination of content and instructional methods delivered by media elements such as words and graphics on a computer intended to build job-transferable knowledge and skills linked to individual learning goals or organizational performance". Architecture for one type of e-Learning Services has been given by Emanuela Moreale and Maria Vargas-Vera **(Fig.5)**. Today's e-learning models do not vary much from this model. The striking point in this is the use of AI for prediction of learning curve by the e-learner.

Ido Roll & Ruth Wylie (2016), in their research article on 'Evolution and Revolution in Artificial Intelligence in Education', identified the evolution of use of AI in e-learning platforms. intelligent, adaptive, or personalized learning systems are increasingly being deployed in schools and universities, 21 around the world, gathering and analyzing huge amounts of student big data, and significantly impacting the lives of students and educators, (Wayne Holmes, 2019).

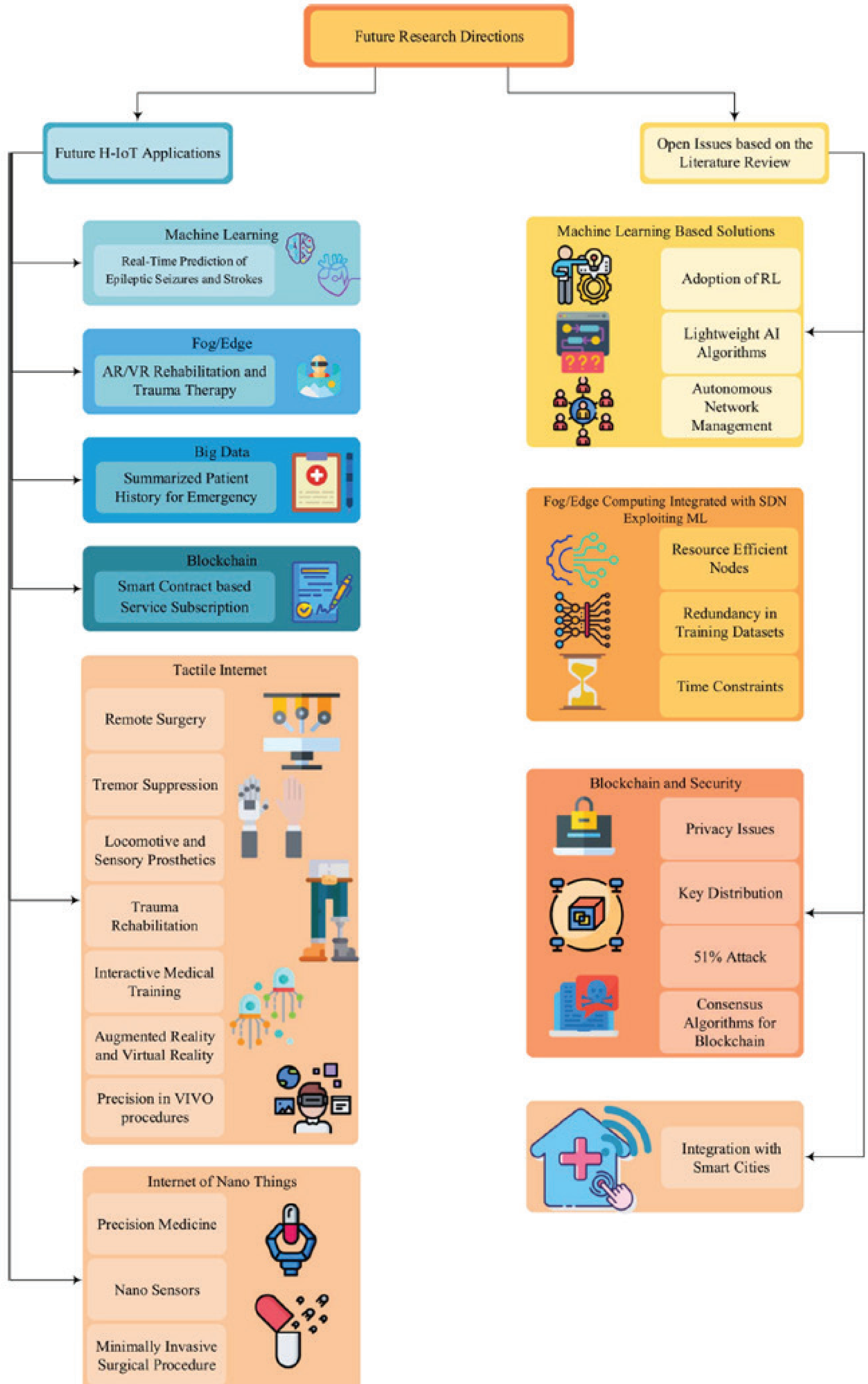

Fig. 5 : Future research directions in Healthcare Internet of Things (H-IoT) (Yazdan Ahmad Qadri et al, 2018)

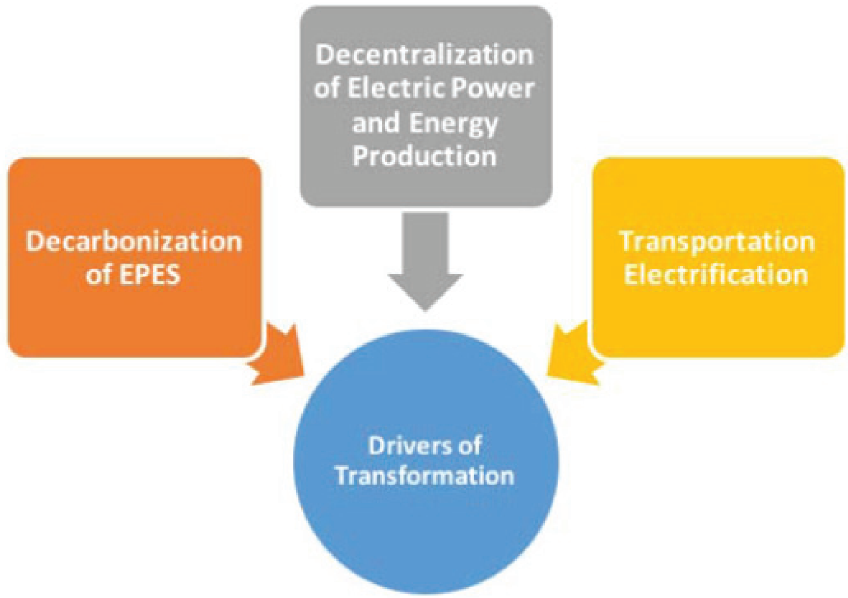

Fig. 6 : Major drivers of the transformation in electric power industry (Guneet et al)

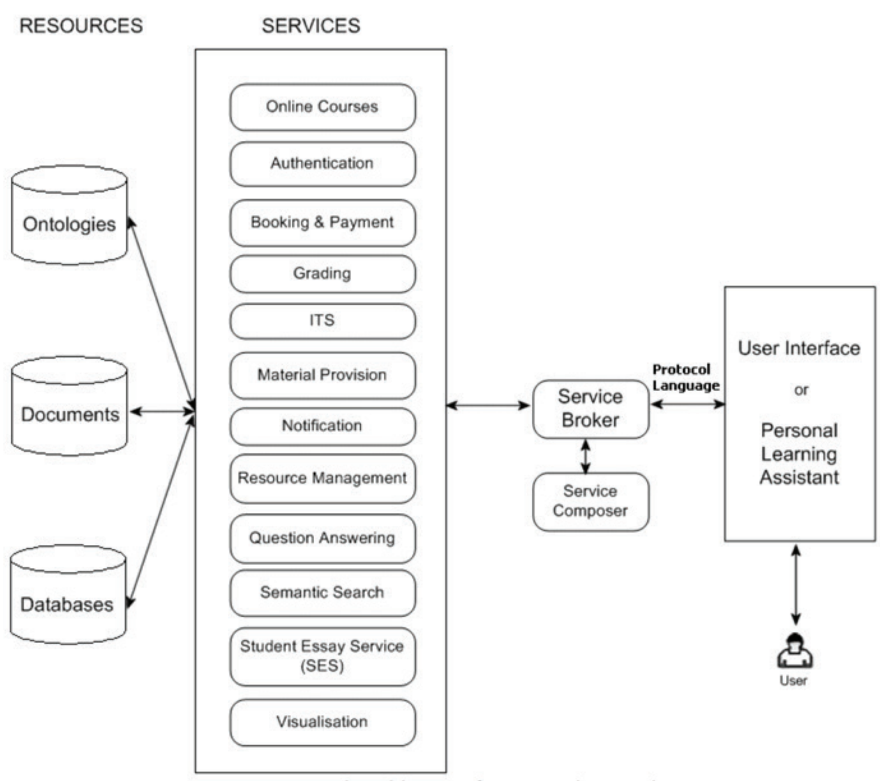

Fig. 7 : Architecture for e-Learning Services (Emanuela Moreale and Maria Vargas-Vera)

CONCLUDING REMARKS

Rapid transformation of transport, manufacturing, online businesses, agro-technologies, and energy and environment sectors is on the card. AI, Machine Learning, increasing layers of automation and advent of new and smart materials and networked manufacturing systems shall be the major force driving growth and development in future. The future of job shall undergo a rapid and disruptive transformation in the coming years now that the power of innovation and human ingenuity has been vastly unleashed with the advent of the digital age that has descended in all spheres of human activity including industry, trade and businesses.

With automation business processes will change and thus many people need to transform their skill set to abreast with the changing times. However, the scale of shifts in the labour force is uncertain as of now assuming the capability to adopt to changing technologies and work environment. In the past also, we have seen that with the advent of technology the magnitude of shift seen in people from agriculture to technology jobs did not create mass unemployment. Future cannot be predicted now, but we know for certain that humans will still be needed alongside automated and intelligent machines. The only thing that can be predicted right now, is that, the skill set of individuals would change and efforts should be made to adjust the education and skill contours of the current and future student community in colleges and universities to prepare future ready professionals for tomorrows technology intensive work environment.

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Author's Profile

Shri B V R Mohan Reddy has been the Past Chairman of NASSCOM (2015-16) and CII-Southern Region (2008-2009), and the current Chairman of CII National Education Council. He is also the Founding Director of T-Hub. Shri Reddy has also served as the Chairman of the Board of IIT-Hyderabad, IIT-Roorkee, Board Member at University of Michigan College of Engineering, USA, and ASCI-India. He has pioneered global ER&D services from India contributing to about $ 5 billion in cumulative exports.

Shri B V R Mohan Reddy has been the recipient of Padma Shri in the year 2017 for his contributions to trade and industry. Commensurate to his contribution and stature, Shri Reddy has also received Distinguished Leadership Award from American Society of Mechanical Engineers (CIE Division), Distinguished Alumnus Award from IIT-Kanpur, Lifetime Achievement Awards from Hyderabad Management Association (HMA), Hyderabad Software Enterprises Association (HySEA), Centre for Organization Development (COD). He is a Fellow of The Institution of Engineers (India).

Transforming Engineering Education: Emerging Scenario

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Blurb: As the world adapts to the unfolding COVID-19 situation, consumers, businesses, and governments embrace new technologies, powered by digital technologies. New technologies will drive Post-COVID-19 economic recovery,and so engineering as a discipline will be more relevant than ever. It is then imperative that the country's engineering education system gears up for this opportunity,reviews and reforms learning, pedagogy, faculty development, and embraces digital transformation to create a win-win situation for institutions and students.

As I pen this note, the world is in the midst of an unprecedented crisis precipitated by COVID-19 pandemic. The virus spread with astonishing speed to every corner of the world, infecting34 million people, claiming over a million lives (by September 2020), and causing400 million full-time job losses (by June 2020-ILO data). People compare the current financial crisis stemming from the pandemic to the 2008 Global financial crisis(GFC) or the 9/11 terrorist attacks on the Twin Towers in New York and the consequent financial fallout. But I don't think these two events come anywhere closer to COVID-19 impact, in loss of life, livelihood, and the economic impact. The only comparable event in the last century is the Spanish Flu the world witnessed between 1918-1920. The Flu wiped out a third of the world population and impacted all industries, pushing the world economy into a prolonged depression. It took almost 25 years for the world to recover from the Spanish Flu.

Though the current situation may not appear to be of the same magnitude, the COVID-19 situation is still unfolding as the world awaits an effective cure and a vaccine. The total impact may be evident only much later. Six months into the COVID-19 related lockdowns and unlock measures thereafter, the economic situation continues to be grim. In January, India's GDP was expected to grow by 5-6% in 2020. However, at the end of Q1 FY21, India reported a de-growth of 23.9%, its first economic contraction in four decades. The country is expected to contract by around 10% in the fiscal ending March 2021, and the world economy is expected to contract by 5.2% in 2020. Be it automotive, construction, airline, oil and gas,travel or hospitality sector, all core industries are witnessing a serious downturn. Economists predict the imminent restructuring of global economic order as the economic scenario continues to unfold with great uncertainty. They present the plausible economic recovery scenario post-COVID-19, ranging from a sharp V- to a protracted U- to an optimistic J-shaped recovery. Predictions notwithstanding, today's reality is that governments worldwide struggle to balance lockdowns to protect lives and unlock initiatives to safeguard livelihoods and economies.

EMERGING OUTCOMES – DIGITAL IS THE NEW NORMAL

The current situation brings about deep shifts in people's mindsets while bringing about drastic changes in the way people work, live, and learn. Take the case of consumers. Consumer habits are up for a complete turnaround. Today, there is more online shopping than ever before. Home-schooling and e-learning are the new norms. Work from home, workout from home, takeaways/ food deliveries, and virtual socialising are preferred choices. While all non-essential travel has come to a standstill, contactless boarding, thorough health-checks, and sanitizing are a must for air-travel. The one common cord that is connecting all these consumer activities is DIGITAL. Consumers are rapidly adopting digital solutions.

Industries and organizations are pivoting their business models to prioritise customer safety and security and ensure contactless services. Businesses are embracing digital in all aspects of operations. For instance, telehealth/telemedicine solutions are complementing traditional healthcare services. Agriculturists are deploying drones for spraying pesticides due to the need to be contactless. For the same reason, public safety personnel is using drones for surveillance. Sophisticated medical devices are being deployed to make up for the shortage of doctors,paramedics, and healthcare facilities. Education and skill development have embraced technology like never before to ensure continuity of learning. DIGITAL is the new business model.

Governance too has embraced a fairly large amount of digital play. For instance, AarogyaSetu app is monitoring the health of millions of Indians and is playing a critical role in combating COVID-19 challenges. Digital payments have seen a huge surge and smart city concepts are being quickly embraced. DIGITAL is the new governance delivery model.

TECHNOLOGY TO DRIVEPOST-COVID-19RECOVERY

The world recovered from the Great Depression of 1929 after novel inventions opened upnew industries such as automobile production using the assembly line technique, electronic goods production, food processing, and refrigeration,oil exploration, and electricity production. This time around, I believe new technologies will drive the recovery. For this reason, I believe, engineers have an important role to play today and in the future. The signs are quite evident.

As it continues to unfold, COVID-19 is permanently reshaping the world and setting a new normal in every dimension of life and living. On the other hand, technology is accelerating and amplifying the change. While computing technology is growing by leaps and bounds, advances in connectivity are taking computing to the next level with mobile internet, cloud, and IoT. Sensor technology has made it possible to produce miniaturised sensors capable of detecting and emulating human senses such as touch, vision, sound, smell,or even taste. Edge computing has made numerous IoT applications and autonomous driving a possibility. Advances in material sciences have made 3D printing things as big as houses to as small as pins a reality. The strength of the materials today is so good that one can develop non-moving airline parts, using advanced materials and 3D printing. Big data analytics is helping process the billions of data bits and draw meaningful insights. The applications of artificial intelligence and machine learning are cutting across the sectors. Robotics is finding utility in industries ranging from manufacturing to healthcare. So, the latest developments in computers, connectivity, sensors, and algorithms have created new paradigm shifts in terms of what we can achieve.

Therefore,while technology is at the forefront, digital technologies are certainly the game-changers. Take the example of an automobile. As a trained mechanical engineer, I always took pride in my knowledge about a conventional car and its parts - internal combustion engine, auto cycle, diesel cycle, two-stroke/four-stroke engine, or 16-cylinder engine. But the internal combustion engine will disappear sooner than later with the advent of e-vehicles. This would be replaced by just four motors to propel the four wheels. As a result, there is an order of magnitude reduction in the number of moving parts, reducing the maintenance challenges. LiDAR electronics take centre stage in the future car, to generate 360-degree images and process them on-the-fly. Collision control, lane control, automated cruise control are built into the system. So, the automobile of the future, aka autonomous vehicle, is not the pure-play of mechanical engineering anymore. It involves several other disciplines, including electrical and electronics engineering, sensor technologies, robotics, artificial intelligence, network infrastructure, and, most importantly behavioural science, to understand driver behaviour and social expectations. All these disciplines must integrate seamlessly to help produce a fail-proof autonomous vehicle that is safe and has smooth operations. So, the automobile, a pure-play mechanical device once,has become a multidisciplinary system.

One interesting aspect is that this digital disruption and multidisciplinary approach through new technologies is impacting not just one industry, but all industries. In the past, computers and related technologies together were called Information Technology (IT) because these technologies provided information to various stakeholders. Buttoday, they are critical to decision-making and are integral to every functional area across industries. Look at manufacturing, for instance. In the Industry 4.0 paradigm, manufacturing is driven by automation. Thanks to the sensor and communication technologies, the physical world and the virtual world seamlessly integrate into a manufacturing facility. Even sectors such as BFSI, which were averse to technology until recently, are seeing a surge in technology adoption to the point that today, trading happens on the floors of stock exchanges using bots. So, technology use is sector/industry agnostic, limited only by our imagination.

EDUCATION GOES DIGITAL

Let me shift gears and discuss the evolving scenario in the education sector. A guru was once the epitome of knowledge and the only source of learning (Education 1.0). Learning was holistic and life-to-life in a remote gurukul setting. With the invention of the printing press in the 15th century, knowledge and information got segmented, transcribed, documented, and circulated as books and periodicals. Specialisations became the order of the day in higher education. A teacher was still important, but dependence on the teacher came down (Education 2.0). In the latter part of the 20th century, advances in telecommunications and television made remote knowledge dissemination or distance-education a reality (Education 3.0).

Today, the Internet's exposure, expanded bandwidth, affordable hardware, and streaming software have unveiled a new paradigm in interactive online and offline learning (Education 4.0). The content created by the best of the teachers is consumed by students from all corners of the world. This is democratizing knowledge and co-evolving traditional education systems to cater to the requirements of next-generation talent. I see four defining trends emerging in education. Allow me to discuss them in detail.

Learning & Pedagogy

Technology interventions are bringing about several changes in both learning and pedagogy. Today,classrooms have gone digital,or should I say, they have become learning studios! Digital content is going through the transmission towers and landing on student devices. Though we have been seeing this trend for a few years now, COVID-19 has accelerated digital adoption in education, and I believe digital is here to stay in education. By saying this, I don't mean the teacher will not be there or becomes less relevant. I believe a hybrid model holds the future in education and learning. In-class tutoring will be supplemented with online offerings. That apart, synchronous transmission from the classrooms will benefit remote students tremendously.

The key focus right now is student-centric learning. To become more open, flexible, and accommodate the student who is either remote, is working, or prefers to self-determine his/her learning path. Also, a student has so many options today. If he doesn't listen to the teacher in the class, he/she could always go online and source the knowledge. So, the onus now shifts on to the teacher to make sure that the class becomes more interesting and engaging. For this purpose, fractal courses, a new education model that converges formal and non-formal education, are being adopted. This model, which allows breaking down any course into smaller parts of one credit,offers students enormous flexibility in adding credits as per their choice and interest levels. The second model, which is highly effective, is the flipped-classroom model. The flipped classroom intentionally shifts instruction to a learner-centered model in which time in the classroom is used to explore topics in greater depth and create meaningful learning opportunities while students are initially introduced to new topics outside of the classroom as homework.

The average lifespan of a person on this planet today is about 73, and 69 in India. Considering the long life expectancy and the rapid changes in every functional area, it may not be enough for someone to learn one skill as part of their graduation at the age of 21/22 and say, I have all the knowledge required for my entire career. Every profession today demands continuous learning and even life-long learning. Technology will play a key role in facilitating continuous learning at any age. The massive open online courses (MOOCs) will become the new standard of learning. For instance, NASSCOM'S Future Skills platform, an industry-driven learning ecosystem, offers numerous courses and tailor-makes the pace and content of the courses to suit individual learning paths and choices. So, the future of education and learning is student-centric and experiential.

Faculty Development

The second aspect that is imperative for the future of engineering education is the faculty. Today, the country has a shortage of faculty and a shortage of quality faculty. As a country,we have to put in a lot more effort in faculty development programmes. Since technology is constantly evolving, it is highly imperative that faculty knowledge and skills need continuous improvement/updation to maintain teaching standards. Today, there is a practice of hiring PhDs as faculty. They must have done some outstanding work to earn a doctorate. However, a PhD does not necessarily mean he/she is good at teaching. So,I believe a qualifying certificate/degree to teach is mandatory for every engineering faculty.

I also believe recognitions based on seniority need to be complemented with incentivising merit-based excellence, compensation, and career management for faculty. This will motivate faculty to develop their skills and improve performance leading to better teaching outcomes. Simultaneously, institutions should encourage faculty to experiment with pedagogy techniques.

Deepening Industry Linkages

I believe there is a need to strengthen the industry interaction of engineering students. Several government schemes promote apprenticeship and internship. We are not making good use of them, and consequently, the employability index of graduating students is sub-par. The onus is not just on education institutions, though. The industry is an equal stakeholder. Industry and institutions need to work together to create relevant student projects that give them hands-on training to hone their skills.

Further, universities are producing a fairly large volume of research today. However, most of this is remaining as research. It has to be monetised to improve the return on the investment (RoI) spent producing it. To monetise, we need to forge partnerships between industry and academia. These partnerships must be structured and should incorporate project management principles. Another dimension that will accelerate the monetisation of research is building linkages between engineering institutions and the start-up ecosystem. This can be done by setting up mentoring clubs, incubation centres, and exposing student innovations to corporate accelerator programmes and angel networks.

Digital Transformation of Engineering Education

There is no denying that the future is digital, COVID-19, or post-COVID-19.This is the case in education too. So, engineering institutions must embrace digital transformation and create a digital roadmap. Digital pedagogy is very different. Modules of 10-15 minutes duration will become the new normal. In addition to classrooms, we would need studios and video conferencing facilities for synchronous learning of in-person and online students. The back channel text chats can aid in supplemental discussions among students. Breakout rooms, student clusters, social digital clubs, live polls, and many more features would be required to facilitate student brainstorming, group work, and peer learning. Deploy technology that can mime social behaviours. It is important not to envision learning technology as a mere utility but as an academic opportunity. Instructional design, multimedia production, and data analytics are vital. Honestly, developing a virtual culture will require both imaginative and creative implementation, and open leadership and an innovative mindset.

Keeping the emerging trends, student needs,available technology and platforms in perspective, institutions may evolve student-centric programmes. Being student-centred would also mean talking with students about their experiences, and understanding and meeting their needs.

Also, institutions in a virtual learning transition need to refocus, emphasize, and generate a proactive and collaborative attitude. Faculty will have to be motivated, guided, and well-equipped, as their courses and programmes are adapted and re-designed. This entails a smart pedagogic overhaul so that they master the art of distance training and student engagement.

CONCLUSION

The post-COVID-19 world will be very different from the world we know before COVID-19. Even in education. As the pandemic's intensity reduces, colleges may reopen but restrictions on social distancing, sanitising and safety precautions will remain. For instance, classrooms that accommodated 90 students will start accommodating only 40-45 students. To ensure continuity of education amidst the challenges, educational institutions need to be realistic about the challenges, yet be steadfastly optimistic in ingeniously devising ways to engage with students and create a win-win situation for both institutions and students.

Author's Profile

Shri R S Sharma

Former Chairman & Managing Director of NTPC &
Former MD & CEO of Jindal Power and Former MD Bajaj Power

Shri R S Sharma is a renowned Power Sector professional with a collective experience of more than 49 years in the power sector. He has headed 3 large power utilities - NTPC, Jindal Power & Bajaj Power.

Shri Sharma Started his career in MPEB in Korba in 1971, then joined NTPC in its formative years in 1980 & worked in its multiple power plants across the country before heading it as a Chairman & Managing Director till 2010. Post Retirement from the Public Sector in 2010 at the statutory retirement age of 60, headed Jindal Power till 2015 followed by Bajaj Power till 2020 retiring then from the Private Sector.

During the long tenure in the power sector, Shri Sharma worked deeply in all the fields of power generation. He is an enterprising field engineer who enjoys working directly in the power plants & interacting very closely with all the executives therein. Pioneered many initiatives towards achieving higher efficiency in power generation & re-engineering and set many country wide records. In project management practices, hold Certified Project Director Membership level 'A' by IPMA. He is a 'Fellow' of The Institution of Engineers (India) and has been honoured with several prestigious awards and recognitions including Honorary Fellowship Award from International Project Management Association; Fellowship of World Academy of Productivity Science; and Leadership Award for Sectoral Excellence from Amity School of Business.

Energy of the Future: Evolution or Revolution?

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PREAMBLE

Demand for energy shall be growing globally due to economic growth and growth of population, although extent of demand growth may vary depending upon developed countries or developing countries, available sources and environmental issues. Various organizations like IEA, IRENA, World Energy Council, BP, McKinsey, Shell Energy and many reputed organizations have given projections for Energy Outlook 2050 / sustainable development scenarios targeting the limit of global temperature rise to less than 2 degrees and close to 1.5 degrees and the resultant reduction of CO_2 through various data assumptions and modeling. It demonstrates that future growth of the energy shall be significantly influenced by environmental concerns, cost of power and safety. All have projected their scenarios considering 2 key points (1) requirement of global temperature rise below 2 degrees and (2) considering present policies of various countries. How correct the final scenarios are will depend upon how correct the various assumptions made in their models are and whether they are close to the actual realized path. In my projections, I have taken one key assumption, the "Best case capacity added till date" which also capture the prevalent issues, factors & constraints in different countries. CO_2 emissions data & cost of power from different sources in the paper have been sourced from various studies. Both of these factors – amount of CO_2 emissions and cost of power need to be considered for sustainable energy requirement. As electricity is the most critical component of energy and responsible for majority of CO_2 emissions, this paper is mostly focused on the future of electricity but it also tries to give an equally good picture of primary sources of energy which are Coal, Oil, Gas and Water.

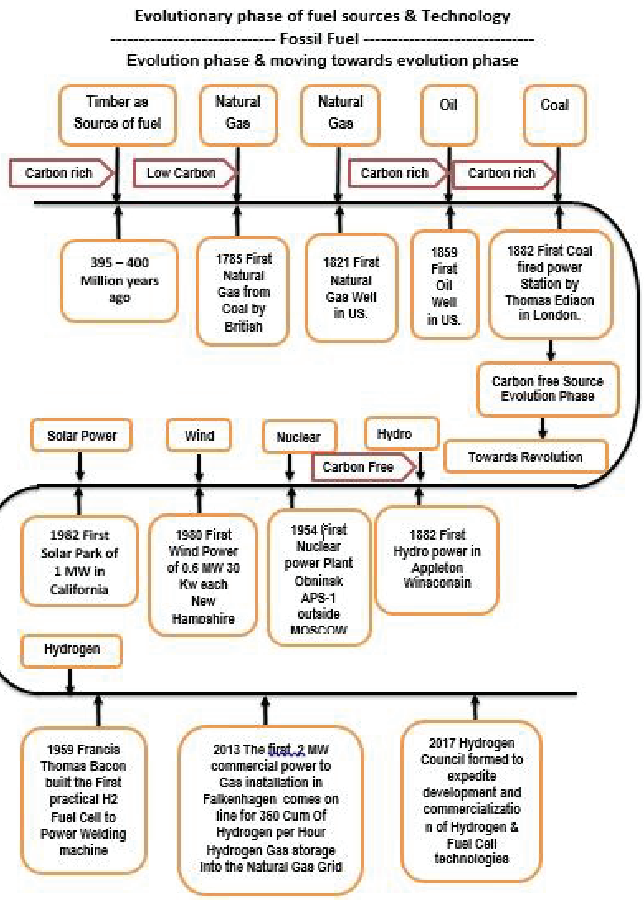
EVOLUTION OF ENERGY

Energy, water, clean air and food are four major elements for human survival. Energy is required for cooking, heating, lighting, healthcare, factories and economic growth activities. Sources of energy are Coal, Gas, Hydro, Nuclear, Renewables and many others which are under development.

Human civilization started with use of timber which is a carbon rich fuel, then Coal, Oil and Natural Gas which being less in carbon are considered as lean carbon fuels. Starting with Carbon rich fuels, the world is now moving towards carbon free sources of energy in the form of Hydro , Nuclear and now Renewables and the emerging fuel of future , "Hydrogen ". Let's see this transformation over different periods detailed in **Fig. 1** below.

The **Fig. 1** shows two very clear eras, a Carbon rich era ruled by fossil fuels and a Carbon free era which is transforming to an era ruled by Solar and Wind Power and then by Hydrogen.

It may be also noted from **Fig. 1** that it takes nearly 70-80 years for a technology and source to get commercialized fully, whether it is Coal or Oil or Natural Gas and now Solar or Wind. With this analogy Hydrogen may take another 30-40 years



more to get fully commercialized. This is what the past historical data imply. However, given the rapid advancement in technology in this digital era, it is possible that this growth can be faster. We shall examine these in detail.

Timber is mostly phased out as energy source except for some parts of the world. Presently, Coal, Oil and Gas have a majority share in the energy landscape. These sources have dominated the energy landscape for the last 100 years or so.

Coal, Oil and Gas are all fossil fuels which produce energy on combustion and in process produce CO_2 which is a greenhouse gas largely responsible for global warming. It is proclaimed that fossil fuels may have a total cycle of around 300 years which means they may last for around 150 years more. Huge amounts of Natural gas have also been found in Shale gas, Shale oil and Natural gas hydrate which when fully explored shall provide much more resources of Natural gas.

Coal is mainly used for generation of electricity and there are sufficient reserves of Coal in the world too.

The table below shows the dominance of fossil fuel in electricity generation.

The trend shows more or less same global level in the last 20 years. However, when we see on a country wise basis, the trends are different.

Table 1: Global trend of Power - Fossil V/s Non-fossil

Year	Fossil fuel	Non fossil fuels
2000	64.95%	35.05%
2010	67.64%	32,36%
2014	67.03%	32.97%
2018	63.00%	37.00%

Source: From sources in public domain

Table 2 : Trend of Generation based on Fossil Fuels in key economies

Year	Countries					
	USA	Germany	UK	Japan	China	India
2016	65.28%	56.15%	52.52%	79.9%	71.49%	80.42%
2019	61%	30%	42%	70%	70% (2018)	77.80%

Source: IEA & CEA for 2016 & 2019, information in public domain

The above table shows that Germany and UK are moving very aggressively towards non-fossil fuels.

Electricity generation by fossil fuels has created huge environmental imbalance due to emission of large quantity of CO_2 and this has alarmed the world and there are very concerted efforts across the globe to contain and reduce the CO_2 emission. As per for the Kyoto Protocol entered in 1997 which came into force in 2005, the year 1990 has been considered as the base reference year for CO_2 in future to contain the global temperature rise. There are herculean efforts to reduce CO_2 with new energy sources and this is what is going to change the energy landscape of future for reduction of greenhouse gases namely CO_2 . **Fig 2 (i) & (ii)** show the trend of CO_2 as projected by IRENA in their World Energy Outlook 2050.

The above chart is showing a declining trend of CO_2 in developed countries like Europe & US.

There is a renewed thrust and focus in Renewables i.e. Carbon free sources post the 2015 Paris accord, which is well reflected through **Fig. 3**.

REVOLUTION PHASE OF ENERGY

Solar and wind power have crossed the evolutionary era and they are totally commercialized and ready to take the world by storm. Falling prices of Solar and Wind and their huge availability has given a great hope to the world towards a net zero carbon future.

Let's see the trend of prices of Solar Power and Wind Power, the two prominent sources of renewable energy under large scale development across the globe. **Fig. 4** gives the declining price of solar panels over the last few years.

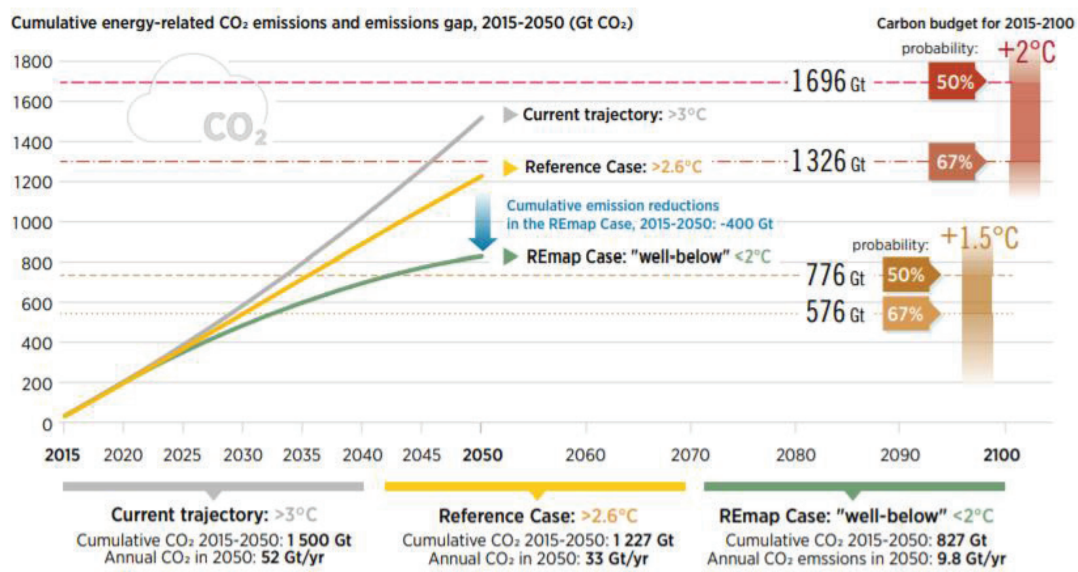


Fig - 2 (i)

Source: IRENA - World Energy Outlook 2050

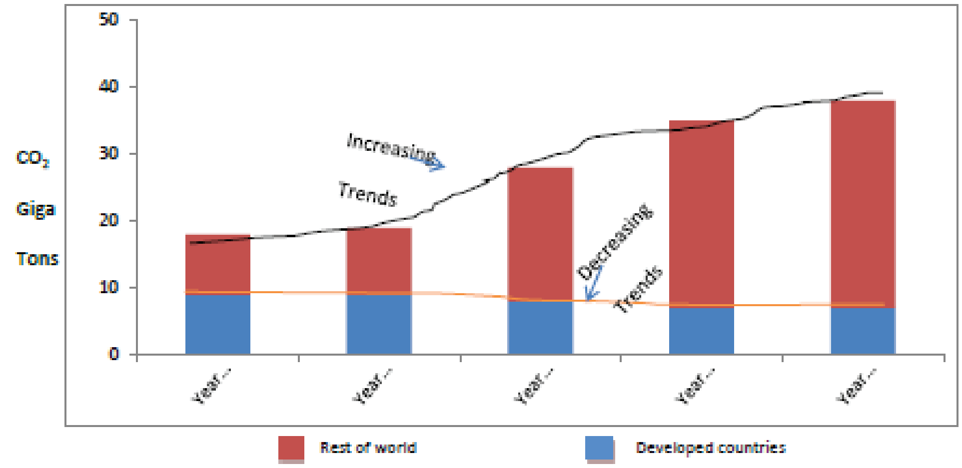


Fig. 2 (ii) : Trend of CO_2 since 1990

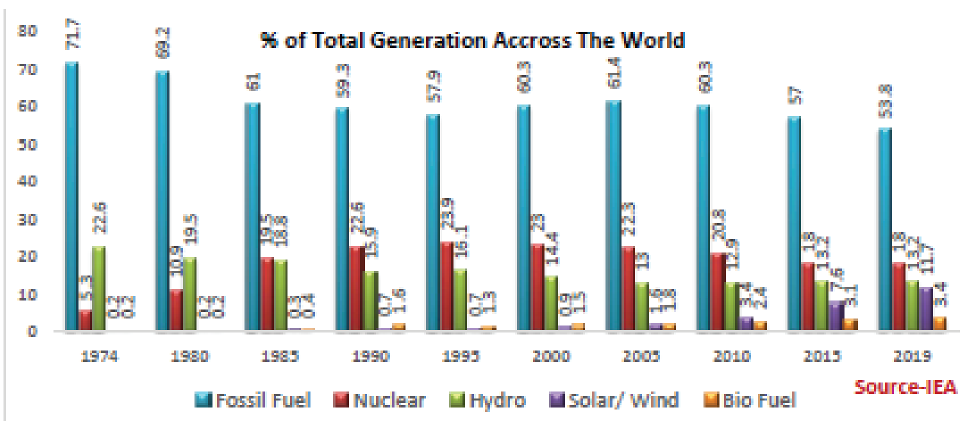


Fig. 3 :

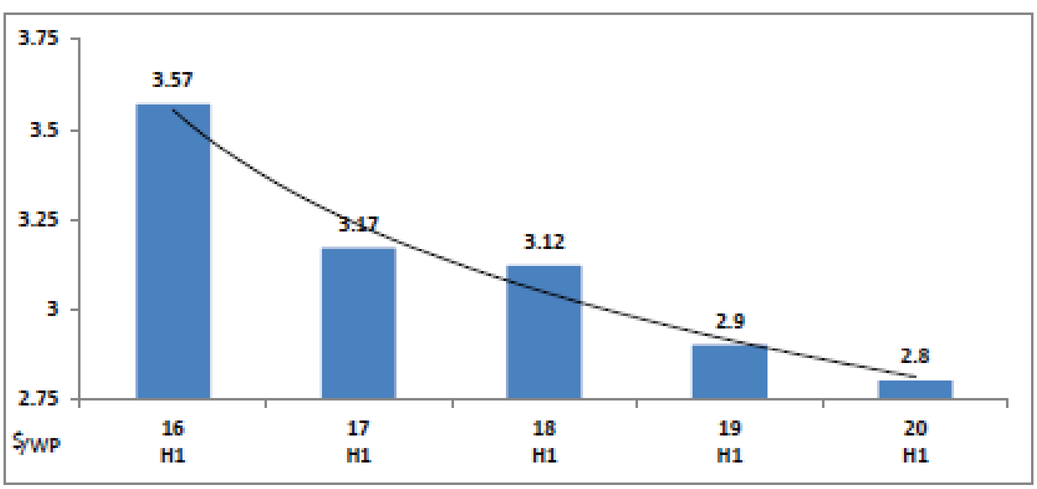


Fig. 4 : Trend of Solar Panel pricing

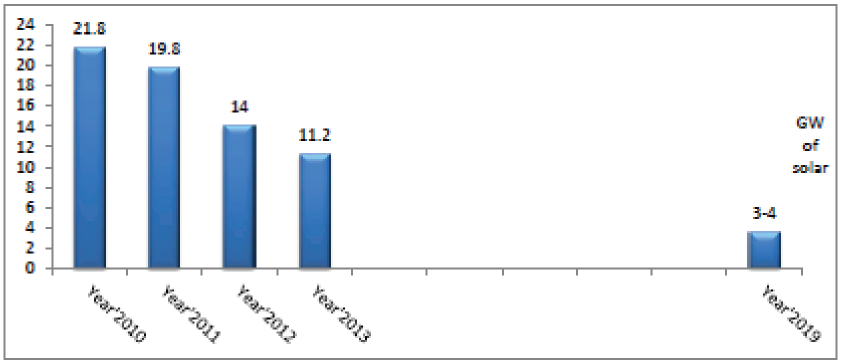


Fig. 5 :

This is the impact of large scale supply of solar panels to meet Solar Power growth. Changes in solar power panel cost over time can be explained by Swanson's Law which states that price of solar PV modules decrease by 20% for every doubling in solar capacity.

Let's see **Fig. 5** for Solar Power price trend.

The above figure proves Swanson's theory. Solar power prices have dropped all over the world. Gulf region has seen the lowest tariff particularly UAE and Saudi Arabia in the range of US cents 1.35 to 1.80 per kWH. In August 2020 another record of lowest cost of Solar Power is seen in Portugal with tariff discovery of US cents 1.34 / kWh for 700 MW solar power project. In rest of the world it is in the range to US cents 3.14 to 3.4 per kWH **(Fig. 6)**.

The story of wind power, another source of renewable power having an increasing trend is similar. In the last one decade there has been a drastic reduction in cost of power from wind. **(Fig. 7)**.

These prices are much lower than prices from Coal Power Plants. This shows how tough a scenario lies before fossil fuels particularly coal not only due to higher emission of CO_2 but also with regards to cost of power.

Solar Power and Wind Power both are intermittent sources of power as solar power depends on the rays of the sun and wind power depends on speed of winds which are not available 24X7. However, power is required 24X7. This drives the development of storage technologies in form of Storage Batteries, Hydrogen and Pump Storage

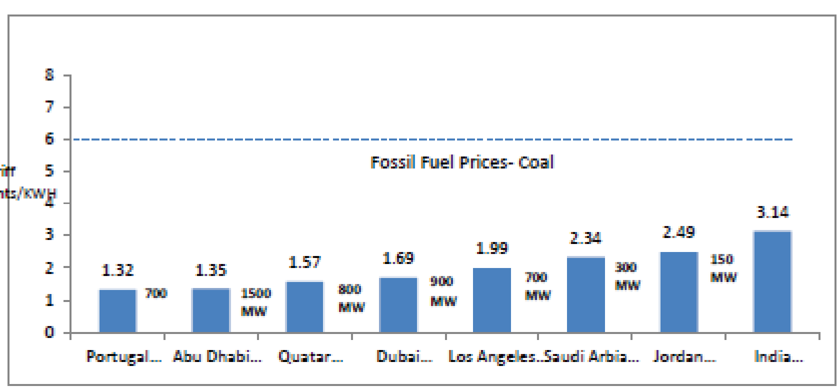


Fig. 6 :

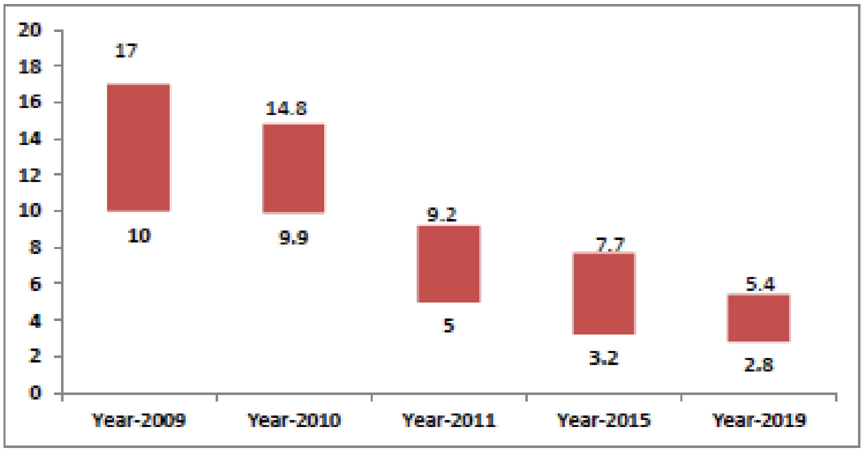


Fig. 7 : Trend of Wind Power cost

etc. Out of this Pump Storage is a proven source and has been in use since ages, only it's large scale development has been an issue due to tough terrain and geology along with sources of water.

Most promising future storage technologies are Batteries, Hydrogen storage and Compressed Air Storage, the key factors for which currently are the transportation network and their present costs, but these concerns are projected to reduce rapidly in a time span of 10-20 years or so with large scale development .

With storage technologies getting matured fully and with the cost economy of Solar Power and Wind Power, renewables shall occupy a much larger space than fossil fuels. Whether it happens by 2050, as is being targeted by the global community under Paris Accord 2015, will depend upon various goveronment policies, investment flows and right regulatory and market dynamics.

FUTURE OF FOSSIL FUELS

Will fossil fuels get totally driven out? It does not look to be so. Natural gas is going to stay because of two factors, one is - this itself is a low carbon source and secondly it's a very flexible source of power generation just like hydro, which makes it into not only a superior fuel but also a must have source for the future.

With increase of Solar and Wind capacity, it's flexible generation which shall be sought more and more for the large scale stability of grid as only storage standalone may not be enough to meet 24X7 requirements. Moreover, the availability of Natural gas with discoveries in Shale gas makes it much more assured.

In future Coal and Natural gas shall be required to operate at much more higher cycle efficiencies to the level of 46-50% for coal and nearly 60% for gas turbines. They will require to be mandatorily fitted with CCU technologies i.e. Carbon Capture and CO_2 utilisation if they have to survive.

Coal Plants will require to be proved for more flexibility than at present. Flexibility means electricity generation, ups and downs and stable operation at lower loads, which shall be a mandatory feature in future. But to say that coal will get driven out, is not doable for all countries though some countries may be able to do so particularly European countries. In countries like India and China where Coal based power plants are in majority, the share of Coal is going to last much longer beyond 2050 for the security of energy for them. As seen in **Table 1** even in 2020 fossil fuels are having dominant share in the global arena.

FUTURE PROJECTIONS OF ELECTRICITY SOURCES AND TECHNOLOGIES

In order to look to the future of electricity sources and technologies, the author have gone extensively through various articles / reports published by EIA , IRENA, World Energy Council, McKinsey, BP and Shell Energy about their projections. In all the studies and projections following emerge as key sources and technologies of the future.

1. Renewables
   - Solar
   - Wind
   - Bio fuel
2. Hydro power
3. Nuclear power
4. Hydrogen
5. Natural Gas
6. Coal plants with High Efficiency and low emission and with CCUs
7. Storage technology
8. Distributed Generation
9. Energy efficiency and Energy intensity
10. Flexibility and Market ecosystem.

These ten will lead the future of landscape not only for electricity but also for the entire energy spectrum. It's worthwhile to examine their development in brief to gauge the direction in which these are moving which shall provide an idea as to what shall be the future of energy in the world.

Table 3 : Solar power capacity addition by some key countries

Country	Capacity added in 2019 (MW)	Cumulative capacity till 2019 (MW)
China	30100	204700
USA	13300	75900
India	6546	34627
Japan	7000	63000
Vietnam	4800	NA
Spain	4400	NA
Germany	3900	49200
Australia	3700	14600
South Korea	3100	11200
UK	NA	13300

Source: From information in public domain

Solar Power

Solar Power has taken the world by storm and in the last one decade there has been large scale capacity addition of Solar Power. In 2010 Solar capacity was just 40 GW which stands at 620 GW in 2019, nearly 15 times more than in 2010. This reflects the focus of world towards greener power. If we look to some key countries in adding Solar capacity it gives a very promising scenario.

India's scenario has been also very promising, shown in **Fig. 8**.

Fig. 8 : Solar capacity addition in India over the last decade.

It's a very spectacular growth. The world will certainly see larger capacity additions across the globe due to falling of prices of Solar Power quite steeply.

What shall be the capacity added in future through Solar as a source? Considering the Solar Power addition in year 2019 which was the best year for solar capacity addition till date and considering this as number as the average addition of solar power in the future per annum in future then following scenario emerges:-

Solar capacity addition in 2019 was 115 GW as per report from IEA , which we consider as the "Best case capacity added till date", we see the following numbers for Solar Power capacity in different years -

2020 : 620 GW

2030 : 1887 GW (2037 GW by IRENA in PES)

2050 : 3880 GW (4447 GW by IRENA in PES)

Source: Global renewal outlook 2050 by IRENA

This scenario is close to PES scenario given by IRENA but lower than their projection.

Wind Power

Wind Power is one of the fastest growing renewable energy technologies. Its prices are also falling.

A technical committee of Works Association has projected a potential of 95000 GW. Considering the ample source availability, large market potential and cost competitiveness of onshore wind (i.e. land based wind plants, as opposed to offshore i.e. water based) is expected to drive overall renewable growth in several regions. China having potential of 2000 GW and India having potential of 300 GW shall lead the installations by Wind Power. During initial years, Europe was driving the Wind Power and in 2010 it accounted for 47% wind.

Considering the best capacity addition in the year and taking as annual average in future, the following picture emerges.

Highest capacity added in year 2017 – 60 GW (Source : WWEA), which we consider as the "Best case capacity added till date", we see the following numbers for Wind Power capacity in different years -

2020 : 650 GW

2030 : 1250GW (1455 GW by IRENA in PES)

2050 : 2450 GW (2434 GW by IRENA in PES)

It matches with projection of IRENA.

Bio-fuels

The Global capacity of electricity by Bio fuels is approx. 140 GW (Source - Stastica), which is nearly 6% of total renewable.

Bio fuels are the most prominent sources of energy. In Africa, more than 90% of primary energy comes from Bio mass. It's a good source of electricity generation. In the year 2000 Bio mass was the second largest renewable source after Hydro. It changed after rapid growth in solar and wind.

Following are the main sources of bio-fuels:-

i. Agriculture - This is a significant contributor to the biomass supply.

   Globally 10% of all biomass comes from agriculture sector. Agriculture crops are having varying uses in supply of Biomass like Maize, Sugar Cane and Oil Seeds crops which are converted to produce Liquid Bio Ethanol and Biodiesel. Cereals and Sugar crops can be used for producing advanced Bio feel biofuels via the use of residues like straw , husk and stalk etc.

ii. Waste - Municipal and industrial waste are two important sources of bio energy production. Together they contribute to about 3% of total biomass supply. All the agricultural crops residues, wood chips etc in form of pellets are good sources of electricity by co-firing them with coal.

Government policies and regulatory policies will need to align for more investment into the harnessing of Bio fuels.

Let us assume that the Bio fuel percentage in Power capacity may remain same at 10% of renewable capacity in the future also, which may bring their total capacity to be around 500 GW.

Hydro

This is the most perennial source of electricity which is renewable and can be generated in a flexibly with quick start up and ramp up / ramp down features. The Hydro capacity of th world was 1189 GW in 2019.

Best capacity added scenario in 2019: 21.8 GW, which we consider as the "Best case capacity added till date", we see the following numbers for Wind Power capacity in different years.

2019 – 1189 GW

2030 - Approx 1400 GW (1356 GW by IRENA)

2050 - Approx 1800 GW (1626 GW by IRENA)

Issues with Hydro are their long gestation period and issues with respect to resettlement and rehabilitation of large population and resultant economic issues.

But Hydro development is inevitable in the world. All countries will be require to work to harness theirs full Hydro potential and align with suitable policies to execute them if the renewable targets are required to be met as there is no match to Hydro so far flexibility is concerned and large scale Solar and Winds are sustainable with flexible generation only.

Nuclear

Nuclear energy is cost intensive and has long gestation period for their construction and commissioning. There are safety issues associated with it owing to its radioactive nature alongside disposal of nuclear waste. It's Carbon free electricity and has tremendous potential. Nuclear capacity in the world was 443 GW by end of 2019.

In 2011 the combined effects of a massive earthquake and tsunami triggered an accident at the Fukushima Daiichi Nuclear Power Plant in Japan and led to an unfortunate decision by Japanese Authority to force the evacuation of nearly 200,000 people. This event and many others in the past, have dented Nuclear power capacity addition in the world. IEA has projected the following growth potential for Nuclear Power which shows very nominal growth in next 30 years as against other carbon free sources.

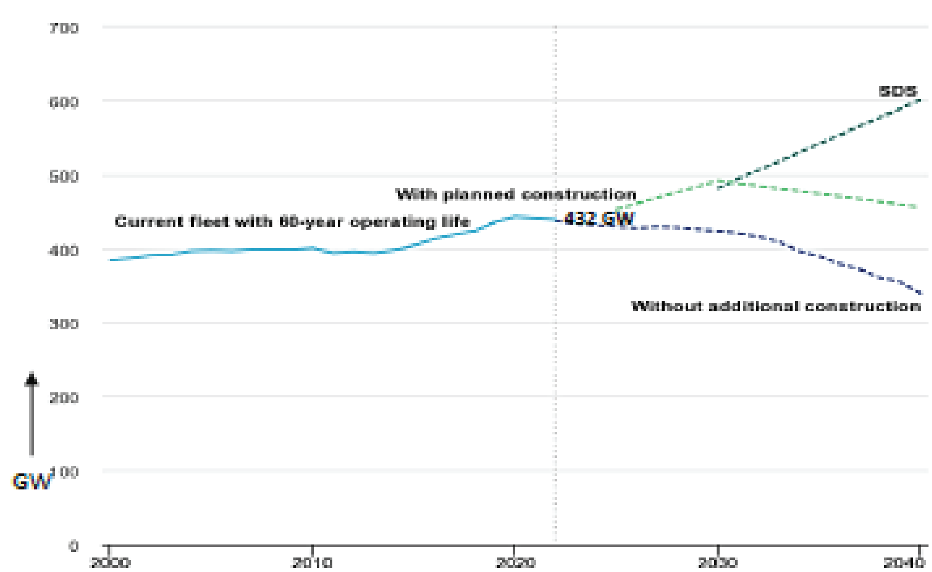


Fig. 9 : Nuclear Power Trend

Source : IEA – Nuclear Power

Hence nuclear may not contribute additional generation in the horizon to 2050 due to decommissioning of some older units. However, countries like China and India do have a plan for sizeable addition of nuclear generation.

Hydrogen

Hydrogen is the biggest emerging source in the energy landscape of the world and it may be emerging as one of the biggest revolutions in future in transport sector and power sector both. Car manufactures are already working on Hydrogen driven cars. It can generally travel 100 km with 1 kg of Hydrogen. Present cost of Hydrogen is 2-3 dollar per kg. It is already cost competitive when compared to petrol and diesel driven cars. Present source of Hydrogen is mostly by reforming process of hydrocarbons which is called as brown Hydrogen. World is moving forward for green Hydrogen production by electrolysis process called as green Hydrogen with

Solar Power as a source of power. It's green Hydrogen which is needed towards decarbonisation as the reforming process for brown Hydrogen requires Natural Gas which is not carbon free. In future the cost of Hydrogen is expected to drop further with large scale production which, may lead it to occupy larger space in the energy sector. But it will be transport and storage infrastructure which shall be crucial for multipoint use of Hydrogen as shown in the **Fig. 10**.

Car manufactures are working for Hydrogen driven cars. Operating cost though may be lower but the cars might cost more and that will be the issue that might come in the way of its large scale commercialization. It's the transport and storage infrastructure of continuation line shall become crucial for its large scale multipoint uses for which Governments will need to find solutions.

GE and Siemens are working on pilot projects for use of Hydrogen in gas turbines and when successful and commercialized the power sector may find its large scale implementation. The world is very closely looking and monitoring its growth.

Natural Gas

Natural gas produces less CO_2 than Coal. It has a feature of quick start and start up with gas turbines coming to full load in 10 minutes and steam turbines with combined cycle plant taking normal time as in Coal plant, but gas turbine itself provides a big back up power.

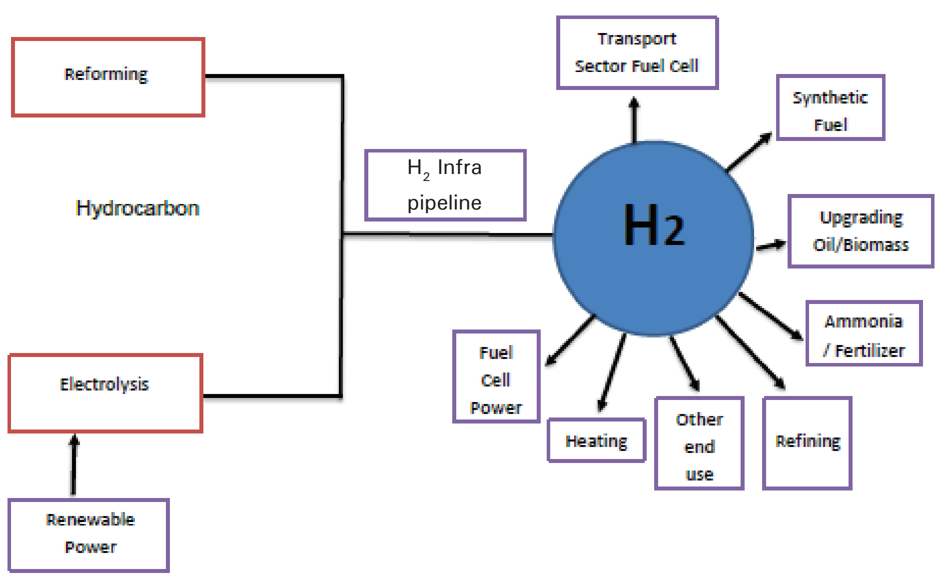


Fig. 10 : Hydrogen wide applications

The author proposes that Gas Plants shall be required to be integrated with renewables for the security and reliability of supply if we want to move towards large share of renewables (which are intermittent power). The California crisis in September 2020 is a clear message around what could go wrong with very aggressive share of renewables without having a strong back up. Import of power under such situations may not work and either of Hydro or Natural gas fired power or coal plant is an essential part of grid.

The world is moving towards very high cycle efficiency for gas Plants to the level of 60-65%.To make the Natural Gas carbon free some utilities across the world are installing CCU i.e. Carbon Capture and Utilization Plants. How economic and reliable will this be, will be seen over a period of time before any large scale materialization of carbon capture and utilization happens.

Research is also in progress for feeding Hydrogen with Natural gas into gas turbines which can further reduce the CO_2 from gas fired plants. But the key issue will remain around the availability of green Hydrogen for this purpose.

Various publications show increasing trend of Natural gas till 2040, but do they include CCS projects too, which raises a question mark.

Coal Plants with high efficiency, low emission and with CCUs (Carbon Capture and Utilisation)

Coal Plants are the biggest emitter of CO_2, as they continue to supply around 35 to 40% of total CO_2 across the globe. With large scale implementation of renewable capacity due to its falling prices and CO_2 reduction targets, it is coal whose future is very uncertain. But there are large economies like India, China and Australia where Coal based Power Plants are meeting country requirements ranging from 60-80%.Exit of coal based plants does not look to be viable unless sufficient capacity of renewable to meet not only present demand for electricity but of future growth. This needs to be coupled with availability of flexible generation and of storage technology becoming commercially competitive and available .

Coal Plants have proved to be the most reliable and safest plant in the world. They can operate from a low of 20/25% to higher utilization level of 100 % on a sustained basis. On reliability front Coal Plants can be rated higher than Natural gas and Nuclear power plants..

Newer Power Plants are being built with flexible features and faster ramp up / ramp down. These features make it more suitable to operate in conjunction with renewables.

China is still adding coal based capacity but all their new built plants are having a cycle efficiency of between 46-50%, adopting clean coal technology and having very low emission levels (practically very marginal values). I feel this is the need of the hour. Instead of thinking of exiting Coal based Power Plants there is a need to make CO_2 utilisation more commercially competitive into either converting it into oil or then use in power generation as Super Critical CO_2 for which there are research works happening. Government policies need to be directed towards capture and utilization of CO_2 more than to exit coal based plants.

Presently there are 21 CCUs Plants operating in the world across different sectors. In future Government policies may be directed towards installation of CCUs in all fossil fuel based power plants.

Hence, the future of fossil fuel based power plants will stay only with higher efficiency to the level of 45% and above and CCUs.

Though most of the publications are towards exit of Coal Plants in the horizons of 2050 but my analysis says that they are going to stay but with reduced share with higher cycle efficiency and inbuilt feature of CO_2 utilization to limit emission of CO_2 into the atmosphere.

Fossil fuels presently contribute about 4165 GW of energy. We can consider just 5% additional capacity mainly from India, China and other developing economies with a projected generation capacity of 4350GW by 2050.

Storage Technology

The world is very eagerly looking for the commercialization of large scale storage technology. The storage technologies which are being projected to become viable are the following:-

a. Storage battery

b. Pump storage

c. Hydrogen storage

d. Compressed Air Energy Storage - CAES.

Undoubtedly storage technology development is the clear path towards decarbonization of the energy. It is being projected that grid scale battery may become commercially viable by 2030 - 2040, but whether this will be able to take space of Coal Plants or Natural gas plants even at theirs best commercial availability needs to be seen. Already apprehensions are getting raised about their life and disposal after useful life which may pose a much bigger challenge. Another issue that remains with batteries are, they may be suitable for peaking requirements only, rest of the time when solar and wind will not be available there will be need for other sources too. But I hope technology shall find right solution to this.

Pump storage is a proven and commercially prudent source. There is need for perfect alignment of Government policies to implement it. Pump storage is one of the sustainable technologies which must be pursued as storage technology. Present capacity of Pump storage is around 121 GW. IRENA has projected to the level of 200 GW by 2030 and 300 GW by 2050.

Hydrogen is the gas for future and if storage and transport become commercially viable this will prove to be the game changer for storage technology. But the world be will required to pursue both green and brown Hydrogen. Exploring the green option alone may make it a costly proposition.

Compressed Air Energy Storage (CAES) system is a commercially proven technology and there are two CAES operational in the world (1) USA (2) Germany. Inspite of commercially proven, this has not penetrated much in the power sector, might be due to lesser requirement felt so far. But with the rapid development of Solar and Wind, CAES may find its place in the future energy storage options. Out of all 4, this has huge potential and is projected to be capable of higher power output.

Distributed Generation.

With the advent of Solar PV and cheap wind power and commercialization of storage technology, Distributed Generation has a great future. A typical feature of distributed Generation is shown in **Fig. 11**.

Problems will however remain with integration of Distributed Generation with large scale grid power for reliability at interconnection points. There will be a need of proper technical code and regulatory practices to guide this transition. It appears that Distributed Generation has good future and will become inevitable in future of the energy landscape of world.

Energy Efficiency and Energy Intensity

This is the one single most critical factor to be realized for meeting the goal of decarbonization of the energy landscape of the world. "Energy efficiency" and "Energy intensity" both are required to be pursued by all countries in the right earnest. This will be one initiative and effort which will be required to be mandated for strict enforcement by all countries.

"Energy efficiency" means utilization of lower quantum of resources for the generation of electricity or fuel consumption. "Energy intensity" means requirement of less energy to carry out the energy processes. One study has projected that energy intensity may drop to just half of present value by 2050. In future, Governments should come up with stringent policies for enforcing energy efficiency and energy intensity.

Regulatory and Market Eco System

For meeting the renewed thrust and need of decarbonization, a very large investment shall be required. Similarly, large amount of research

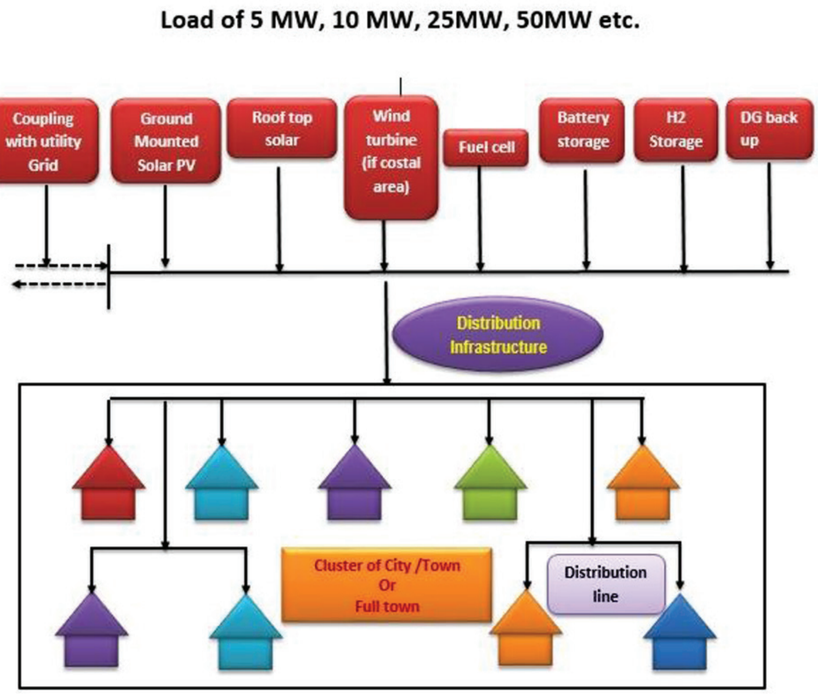


Fig. 11 : Concept of a typical distributed generation – in future

needs to be carried out to reach to higher level of efficiencies and commercializations. Large scale grids may be required to be built to transmit renewable power from the availability to location of users which will require huge investment. All these will also create lot of administrative and implementation issues. Government policies will be required to address this. Presence of many technologies and sources will require proper regulatory and market rules to be framed up so that end user is not put to difficulties and most importantly - there must remain regulatory certainty for the investment made then only investment will flow and energy landscape can transform to decarbonization and also coexist with reliable sources like coal and gas.

ANALYSIS

I would like to summarise the above scenario through energy balance diagram:

- Electricity by fossil fuels + Non fossil fuels = total electricity

  which implies

- Electricity by fossil fuels + Solar power + Wind power + Bio fuels + Hydro + Nuclear + Storage technology + Other renewable sources {Geothermal + future developments) = Total electricity

  (Which are the numbers indicated in blue in above scenarios)

  which implies

- 4350 + 3880 + 2450 + 500 +1800+443 +300 = 13723 GW.

This does not include battery storage + hydrogen as they are emerging and have a great future. We can very safely assume around 14,000 GW installed capacity in the world around 2050, which brings

- The % of Fossil fuel = 31 percentage
- The % of Non-fossil carbon free = 69 percentage

But these percentages may change in case there is more capacity by non fossil fuels or very rapid development in storage technologies or successful commercialization of emerging technologies like use of Super Critical CO_2 in power generation and aggressive transformations in Government policies towards more renewables.

We can finally summarize this as -

- Solar and wind power shall be having the major share in the global electricity generation landscape at more than 44%
- Europe may totally turn to renewables with some natural gas in the back up and US may be operating with renewables and natural gas
- Hydro and Nuclear may hold combined share of a nearly 15%
- Around 10% may belong to storage technology sources plus other carbon free sources
- Together of all carbon free may be 70% of share across the world
- Balance of 30% may be held by fossil fuels mainly coal and gas, more in China, India and Australia. But coal and gas both may require to be equipped with CCU making them costlier in the cost of power
- Hydrogen will emerge as major transport fuel specially in passengers car sector.
- Most of the vehicles on the road will be Hydrogen with fuel cells and EV
- Other technological developments like supercritical CO_2 and hydrogen fuelled gas turbines will push the world towards net zero carbon era and the world will be marching towards carbon neutral economy by start of new century.

Projections by International Organisations

I would like to mention here the projections given by prominent Organisations on the future share of various sources for the energy and electricity.

McKinsey

Renewables are projected to be over 50% of generation by 2035. Gas will continue to grow till 2035 beyond which they plateau. McKinsey has projected that more than 77% of new capacity in electricity sector will come from wind and solar. The share of nuclear and hydro may also grow but modestly. Carbon emission will drop, but 2 Degree path may not be achieved. McKinsey has also projected Non-renewable Hydro will account for one third of total global electricity generation in 2050 than 6% in 2014. As per them Coal will account for 16% of global electricity generation and total fossil fuels may account for 38% of total energy share by 2050.

IRENA

They have given the projection in two scenarios PES and TES.

PES has been defined as scenario under normal government policies and TES has been defined as actions under sustainable scenarios to reduce CO_2 emission to control the global temperature rise to less than 2 degree centigrade and upto 1.5 degree centigrade. Under PES scenario fossil fuel will remain same in 2050 as today's level showing an increase in the role of renewable energy but under TES scenario fossil fuel usage will decline by 75%. They predict that the usage of Coal will decline by 41% in TES scenario in 2030 and 87% in 2050, Oil will decline by 31% in 2030 and 70% in 2050, Natural gas would increase by 3% in 2030 but would decline by 40% in 2050. This is a projection under TES scenario. In PES Natural gas will grow on 40% by 2030.

IEA

In their stated policy scenario (growth in terms of Govt policies) low carbon sources provide more than half of electricity generation, with wind and solar topping the chart, followed by hydro energy accounting for 15% while the share of nuclear energy estimated at 8%.

In a sustainable scenario (to limit the temperature to less than 2 degree and around 1.5 degree centigrade) the low carbon energy sources will witness growth.

According to IEA, combination of Solar, PV and cheaper battery sources will shape the power mix of future. Battery storage is well suited to provide short term flexibility for India needs to meet an evening peak. Oil consumption will continue to grow for long distance vehicles, shipping and aviation's etc but decline for passenger cars.

It means almost all projections point out that following three zero carbon sources will determine the shape of electricity and energy sector of future:

Solar

Wind

Storage technology

Plus contributions from Hydro and Nuclear as of now .

But Coal, Oil and Gas will stay for the energy security around 2050 and beyond as well..

INDIA'S PERSPECTIVE

What does above mean for India which is largely dependent upon Coal with the share of Natural Gas, Hydro and Nuclear all three bring in the lower side. It does not have more flexible generation in form of Hydro and Natural Gas.

We have a picture till 2030 as projected by CEA. Very aggressive target of Solar and Wind has been considered. Though in last 5 years country has seen very aggressive capacity addition in renewable front but corona pandemic has slowed down the growth and it will have long term impact.

Projections by CEA

Source	June 2020	April 2030
Coal	205000 MW	266827 MW
Nuclear	6780 MW	16880 MW
Hydro	45699 MW	73445 MW
Others	14777 MW	10000 MW
Total	371054 MW	831502 MW

So, the capacity addition required over the next 10 years stands at ~ 419000 MW @ 42000 MW average annual capacity.

India's track record of max capacity has been during 12th Plan 2012-17 during which a total of 126964 MW @ 25000 MW / yr combined of Thermal, Hydro and Renewable. Considering 20% additional capacity for next 10 years average it will become around 30000 MW. If we assume additional capacity of nearly 300000 MW combined of all sources thereby resulting in shortfall in projected capacity in 2030 by nearly one lakh MW. This will lead to higher utilization factor from Coal based Power Plants, hence there may be no energy shortage in the horizon of 2030, but extrapolating it to 2050 there will be an energy shortage even if demand growth is from 4-6%. Of-course these numbers will change if country can pursue nearly 40000 MW capacity addition now onwards. from now. But we need to be mindful of the realities and issues at hand before we proceed towards such large additions.

Going forward beyond 2030, India should revisit its strategy of Renewables and Fossil, Hydro and Nuclear capacity in the horizon of 2050 under the backdrop of Paris 2015 accord and country's energy securities on its annual capacity addition target in the following years including technology front for the coal as coal may continue to be the main stay for India. Hence there may be urgent need for looking to high efficiency and low emission units and more efforts for CO_2 utilization initiatives.

This issue needs a through brainstorming involving a wide number of sectoral experts of the Power Sector beyond the current limit group in order to get a much broader picture and actions thereof .

CONCLUSION

Future of the Electricity sources in 2050 may look around as shown in **Fig. 12**.

It may be seen that energy mix may be dominated by renewable energies such as Solar, Wind and Hydro. Energy Storage Systems development and maturity such as Batteries, Pumps Storage, Hydrogen, Compressed Air Energy Storage will influence the further growth of renewables. Nuclear may not play significant role due to higher capital cost longer gestation period and inherent safety issues. Hydro will play a significant role.

Hydrogen shall be the leading fuel out of all in the future.

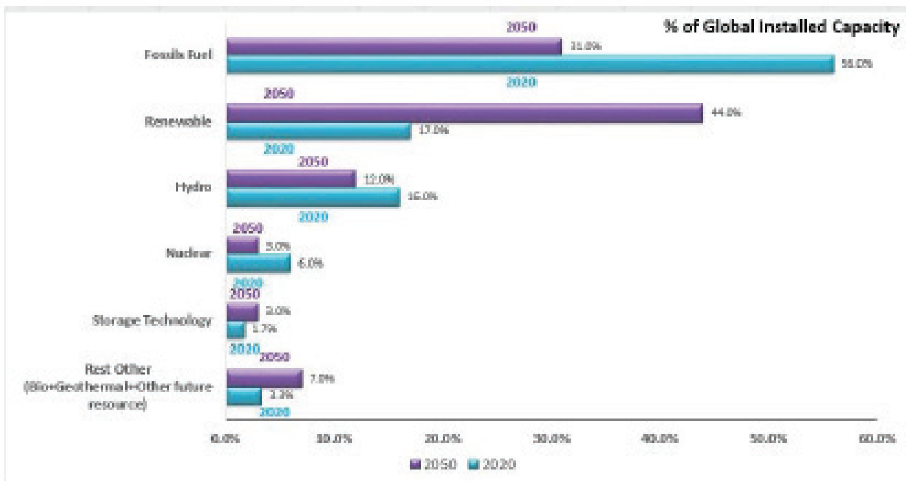


Fig. 11 : Projected electricity generation sources in 2050

The world shall be moving towards a green revolution with carbon free electricity sources dominating the electricity sector.

To conclude, following shall be the key areas having major thrust and shall be very keenly watched and monitored for the rapid growth to achieve CO_2 reduction targets to limit global temperature rise:-

- EVs and Hydrogen together to occupy larger space in transport sector but Oil to stay for long distances and heavy vehicles.
- Cost competitiveness of Storage Technology particularly grid size battery to make renewables more reliable. It's predicted to fall rapidly with mass scale requirement.
- Cost competitiveness of Hydrogen is the key. If it drops, it will revolutionize the total energy sector of the world. Drop in Solar Power will make it happen.
- Fossil fuels to stay for power generation with more flexible features and CCUs.
- Cost of CCUs will need to come down similar to solar and wind in large scale deployment.
- Distributed Generation will find the place in the new green era, mostly dominated by Carbon free sources.

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Er M Gopalakrishnan

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Author's Profile

Er Gopalakrishnan had handled many aspects of Water Resources planning, development, and management over five decades. He is well-known to the global community on water with his rich past links with World Water Council (2004-06) as one of the Governors representing ICID. He is a recipient of the 'Lifetime Achievement award' from the American Academy of Water Resources Engineers. He was nominated by the AAWRE in 2010 acknowledging his lead roles in many aspects of Global Irrigation Advancements as the Secretary General of International Commission on Irrigation and Drainage. He was also conferred citation as Lifetime Achievement Awardee in 2017 Indian Water Resources Society. His key role in designing Tehri High Rockfill Dam, during his stint as Chief Engineer in Central Water Commission's Design & Research Wing, was widely acknowledged and acclaimed. Er Gopalakrishnan was the INCOLD Chairman on the Committee on Seismicity and Dam Designs for well over a decade till 2016 and had been actively involved in successful CBIP Publications on aspects like Sedimentation in Reservoirs and Aseismic Design of Dams and Manuals on advanced analysis in safety against earthquakes. As a member of Project Advisory Committee of IUCN he advocated several aspects like sharing Ganga and Brahmaputra waters for the co-benefit of the two countries. One of the ambitious National Projects, which also has global relevance, is the Interlinking of Rivers. The Institution of Engineers India had the privilege to be invited and render its professional opinion on the Scheme because of its complex multi-disciplinary nature before a Parliamentary Committee of Government of India in 2005. Er Gopalakrishnan as Co chairman of the IEI's subject Committee took the onus of rendering the independent opinion of IEI on its behalf.

He had been co-opted recently to strengthen the Energy Division of NIAS (National Institute of Advanced Studies Bengaluru) conferring the status of honorary Adjunct Professor of NIAS, Bangalore and a Fellow of Indian National Academy of Engineering (FNAE).

Water – the Next Frontier: From Risk to Reward

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PREAMBLE

In hindsight

Born in 1920 IEI, the Institution of Engineers (India) (IEI) is in the Service of Engineering Community since 1920. An Institution of its own unique kind established in the then British Era that encompassed all parts of undivided India pre partition, it played an admirable role in respect of water resources development and management since its formation as a professional body. As its charter indicates, IEI had dedicated itself "to promote and advance the science, practice and business of engineering in all its branches in India". There had been significant contributions in Civil Engineering in India especially in water resources development with magnificent structures all around the nation that were designed and erected for several decades succeeding country's independence.

Gifted with a river system comprising more than 20 major rivers with several tributaries, India is a country considered to be one of the well-endowed nations in respect of water availability. However, with an ever-increasing population and climate extremes now being added on as an additional challenge, the situation is getting severe. Both the extremes of plenty and poverty in water availability impacts it adversely, which is due to temporal and spatial distribution of rainfall.

Not all Indian rivers are perennial. Quite a few rivers especially in peninsular India are just seasonal. Rivers like the Ganga, the Brahmaputra and the Indus which originate from the Himalayas carry water throughout the year since the snow and ice melt of the Himalayas in summer months, besides the base flow, contribute the flows during the lean season.

The country which used to cover the whole of the eponymous subcontinent of India, after attaining independence from Colonial rule in 1947, occupies a large part of the subcontinent but with a changed scenario. Most of the productive irrigated agriculture got lost due to partition to our neighbours. Engineering interventions to harness water by way of dams and storages to ensure better water availability, took country's prime agenda.

India, with only 2.4 present of land area of the world after partition had a challenge to support teaming millions, mostly rural based. Over 70% of them were in rural, and were highly dependent on agriculture when the country got its independence. Engineering solutions of the earlier times were timely when the country gave priority to conceive and build dams, canals, hydropower houses in a big way. The first green revolution to make the country self-sufficient in food security was attainable, thanks to the marvelous and impressive large storage structures across almost all the rivers with dams to cope up and even out water demands in many fronts like water supply, industry and irrigated agriculture. There were significant support from agricultural sciences that could make this feasible.

The Present

India's population, which was less than 400 million in 1950, has now increased to over a 1.35 billion. It is hoped that the population might get stabilized due to various measures by 2050, but, nevertheless, the requirements of at least about 1.6 billion people by 2050 had been justifiably envisioned for planning purposes.

The Future

The SDG Report 2020[1] No.6 Water & Sanitation is amply relevant when we wish to tune our programmes in line with United Nations Global Vision especially in respect of water for SDG 2030. UN Economic and Social Council[2] in its "Asia and the pacific" Regional review on emerging challenges and trends in water resources had identified layers of water hotspots. One notes that India is having 5 out of 10 water hotspots 'consolidated layer' e.g., (i) Increasing Water Scarcity threat (ii) Flood proneness (iii) Drought proneness (iv) Ecosystem climate change (v) Sanitation. In reality, we can find that there is an equal and no less a real threat with regard to other hotspots like (i) high water utilisation (ii) Poor Water Quality and low water endowment (iii) Deteriorating Water Quality (iv) Cyclone proneness and (v) Drinking Water.

The Institution of Engineers intention to bring out 'Engineering for the Future' as its centenary publication takes on board actions that should be the preferable focus on a time frame, just in line with UN SDG 2030 documents. The Institution itself would then be able to participate in country's policy making from an engineering angle so as to gear up its activities in the decades ahead. Water shall remain central and shall be ascending country's agenda at a higher pedestal. As to how one is able to move the position of Water Agenda as a priority issue, given the linkages of water in achieving several SDGs will need discussions. Accordingly, a title "Water – The next Frontier – From Risk to Reward" had been chosen for this paper which, while it starts with country's past significant achievements, moves to the present agenda and looks towards the futuristic scenario.

IEI and Participation in India's Future Agenda in Water Sector

In India, the entire Engineering profession could be brought under the overall umbrella of IEI charter. This is somewhat unique as in most of the cases elsewhere, specific disciplines formulated its own Institutions. The single Institution representing country's overall disciplines of engineering, had its own advantages in ensuring desirable coordinated action plans and policy advice, as warranted. As the largest Membership engineering Institution in the Globe embracing all the disciplines in its fold, IEI could actively contribute to purposeful engineering motivation and action for the progress and welfare of India. It is worth highlighting that it was to this end that the IEI in recent times participated in Government of India's development agenda on Interlinking of Rivers, a futuristic Water Agenda for the decades ahead[3].

WATER RESOURCES OF INDIA – THE BROAD PICTURE

The Setting

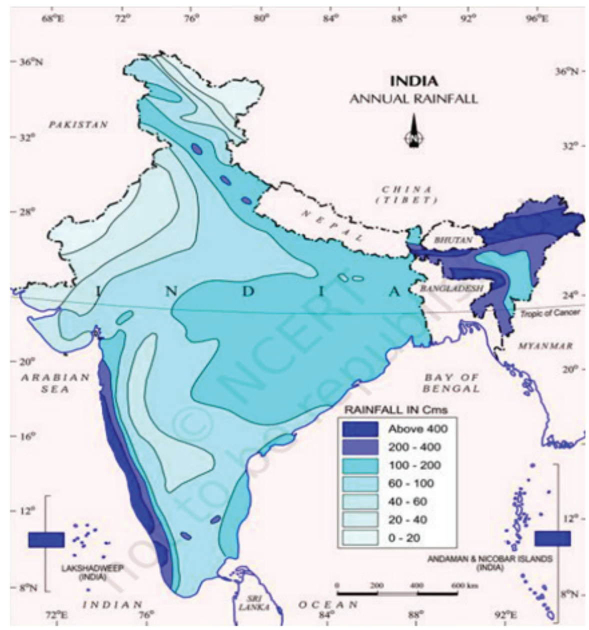
The average annual rainfall in India is 1170 mm, which corresponds to an annual precipitation of 4000 BCM, in volume. Out of this, the average annual flow in the river system of India has been assessed as 1953 BCM. However, over 90 percent of the annual runoff in the Peninsular Rivers and over 80 percent of the annual runoff in the Himalayan Rivers occurs during the 4 monsoon months. The Ganga-Brahmaputra-Meghna system accounts for more than 60 percent of the runoff. Due to this spatial and temporal variation of runoff, floods and droughts had been a common scene in different parts of the country ever since historic times.

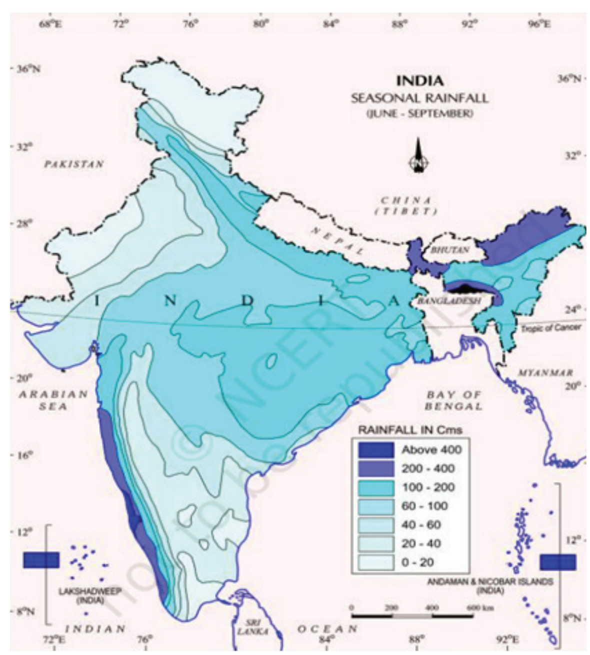
1. Sustainable Development Goals United Nations 2020 https://unstats.un.org/sdgs/report/2020/
2. United Nations Economic and Social Council Document EESCAP MCED Corr.1Table 1 Consolidated Layers of Water Hotspots.
3. The Author of this paper had the pleasure and the privilege to act as the Co Chairman of an IEI Committee on the subject to submit a Memorandum to the Parliamentary Committee constituted to review the Programme of Inter linking of Rivers in 2011 and also participate in a High-Level Committee on the subject that review the Project

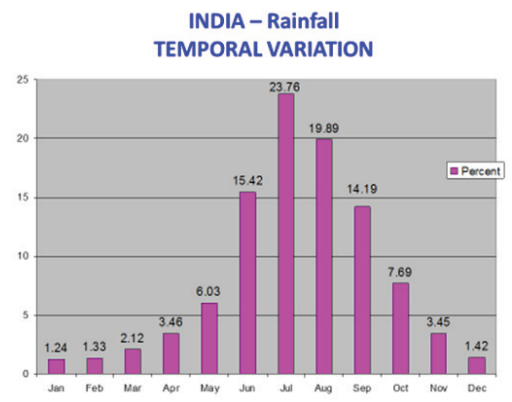
VARIATIONS OF RAINFALL AND THEIR EFFECT

The Monsoon

By far as much as 90 per cent of the annual rainfall in India is received between June and October, the period of the south-west monsoon. The south-west monsoon strikes the Western Ghats and precipitates on their outer or windward slopes, an average rainfall of 254 to 635 cm. The rainfall decreases sharply as it proceeds inland so that on the leeward slopes of the Western Ghats, the average rainfall is of the order of 64 to 102 cm only and by the time the current reaches the Gulf of Cambay, the rainfall is meager. The North east monsoon emanating from Bay of Bengal gives up a considerable part of its moisture during the first lap of its journey along the outer ranges of the Himalayas in Assam and Bengal. At the Khasi Hills near Shillong and its adjoining areas, the highest rainfall averages nearly 1,270 cm, had been recorded. However, by the time this current reaches the westwards to Punjab, most of its moisture is dropped and rainfalls are scanty. These regions not only suffer from insufficient rainfall, but also a wide variation, year to year. In the south-eastern portion of the southern peninsular India, the season of the heaviest rainfall is from October to December, the period of the winter or north-east monsoon. The north-east monsoon is also responsible for the winter rainfall of northern India and a few winter showers over the central and eastern parts of the country.







Between the two extremes of abundant or meager rainfall, lies a vast area where the average rainfall varies from 25 cm to say 178 cm where scarcity conditions and famines occur time to time, consequent upon the vagaries of the monsoons. Statistics indicate that one in five years may be a dry year, and one in ten may be subject to a severe drought. Reducing the misery under such conditions lies in engineering interventions. Large Dams and storages stood recognised as an absolute necessity for Indian conditions to secure water for its welfare.

Engineered Interventions - Dams and Barrages for Water Development

Conceiving storage dams in a well-articulated manner was given thrust in the country soon after independence for several decades. Alongside, continuous efforts to evolve current science and technological development were also going side by side. If one were to look back, neither the seismic considerations nor some of the latest geo-technological solutions were simply available around the decades following independence. Notwithstanding, several bold engineering planning and designs were conceived with the available state of the art technology and structures across rivers, like dams of various types like Masonry, Concrete, earth and rockfill etc were erected. Empirical assessment were utilised when hydrology as a science was at its infancy or simply unavailable in those days!

Better designs and construction of Dams, Barrages etc., to create storages large and small, were possible with increasing technological advancements. Nevertheless, an inter-disciplinary coordination between engineering sciences became increasingly relevant.

Year	Population in Millions	Food grain Production (Million tonnes
1950-51	361	51
1960-61	439	82
1970-71	548	108
1980-81	683	130
1990-91	846	176
1997-98	Nearly 950	194
present	Nearly 1350	Over 290
2050	1640 (anticipated)	Nearly 455

Fillip for dam building activity was facilitated as with the launching of planned development with Five Year Plans which followed the declaration of India as a Sovereign Republic in 1951. Nearly 800 dams were added in the succeeding two decades.

In succession in later decades that followed, numerous dams, barrages and water diversions started taking place. This was ranked next only to USA and China, in numbers,. A look at the statistics between 1990s till the end of 20th century reveals this aspect. That this could immensely help country's self sufficiency in food as well as hydroelectric power contribution to the grid, besides flood control, could reduce the earlier miseries due to severe drought and floods. It was also possible to help welfare aspects linked to water for society like assuring drinking and industrial water supply, environmental security with minimum possible river flows etc., as situations could be addressed in the best possible manner.

Some examples of Large Dams in India (as an illustration) that were brought in during preceding decades since independence

It will remain the pride of Institution of Engineers (India) to capture a glimpse of some of the marvellous engineering structures in water sector hereunder, though the list is quite vast. It is just to respect the space limitations that many other impressive projects are not covered in this paper.

Bhakra Nangal Project

Bhakra Dam has been constructed across river Sutlej, a tributary of river Indus. The dam is a straight gravity concrete structure with a maximum height of 226 m and length 518 m. The dam is part of mammoth multipurpose Bhakra-Nangal Project for providing Irrigation, water supply & power to the states of Punjab, Haryana, Rajasthan and Delhi. The lake created by the dam extends to about 97 km upstream of dam and covers an area of 168.35 km^2. The gross storage and live storage capacity being of the order of 9.62 km^3 and 7.19 km^3.

Two power plants are located on either side of the spillway d/s of the toe of the dam. There are two canal power houses in the Nangal Hydel Channel, and the total installed capacity of Bhakra Nangal System is 1354 MW. The Bhakra dam feeds a network of irrigation canals which command an area of 2.63 MHa in the states of Punjab, Haryana & Rajasthan, in addition to stabilizing and improving irrigation under three existing canal systems.

Nangal Barrage

About 13 km downstream of the Bhakra Dam site, the Satluj River emerges out of the Shivalik Hills at Nangal, to enter the plans of Punjab. The Nangal Barrage/ Dam is built across the Satluj at the point. It is a 291 meter long concrete structure, 27.7 meter high and has a small storage capacity of 30 million cu. m. Equivalent to just one day's supply in the hydel cannel, to take care of the diurnal variations of releases from the dam upstream.

The barrage feeds Nangal hydel cannel which carries a discharge of 354 cumecs, beyond the silt ejectors. This cannel which is 64 km is fully lined. The Irrigation canal takes off from the tail of the hydel cannel. This irrigation system comprises some 1110 km of main and branch canals and nearly 3379 km of distributary channels. The whole system utilizes a discharge of 510 cumec.

The project, on a comparatively modest side, had been on the anvil for many years for the development of the arid and backward areas of East Punjab and Rajasthan, but the partition of India gave a fillip to the finalization of the project in accordance with the 'Indus Water Treaty'.

Damodar Valley Project

The Damodar Valley Project is the first major Multipurpose River Valley Development Project in Eastern India.

The Upper Damodar Basin is wide fan-shaped in nature where the up-valley hill slope is very steep in contrast to the Lower Damodar Basin which is very narrow and elongated with gentle topography. Again, the river flows just in opposite direction of rain-bearing south west monsoon wind. So, during the monsoon period, the lower Damodar Basin becomes saturated first with the monsoon water and when the south west monsoon wind reaches the Jharkhand state and there is heavy downpour; the rain water rushes through the Damodar and causes floods of various magnitudes in the lower segment every year. Therefore, devastating floods of high destructive nature were of regular occurrences for which the river was typically known as the 'Sorrow of Bengal'. Its notoriety was demonstrated by the devastating floods in 1823, 1848, 1856, 1859, 1863 1882, 1890, 1898, 1901, 1905, 1907, 1913, 1916, 1923, 1935 and 1943. While major floods occur at intervals, minor floods are experienced almost every year. Indeed the floods in the lower Damodar Basin have a long history since the first recorded flood of 1730. Apart from the small scale participatory initiative by the local people in managing floods by jacketing the lower course in order to restrict the spreading of the flood water of the Damodar River, the first worth-mentioning project on part of the British rulers was the excavation of the Eden Canal so as to divert the monsoon flood water into the Bhagirathi-Hugli River. However, this venture was not so effective in mitigating the agony of people of the lower Damodar Basin. The Central Governments' initial focus on DVC is something similar to TVC in USA and unique in itself where multi state participation through an agency like DVC with Central Governments oversight was possible.

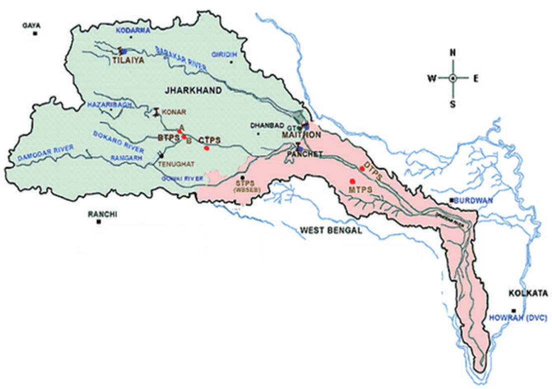


Fig: Locations of Tilaiya, Konar, Maithon and Panchet Hill dams in Damodar valley

Assigning Flood control as a primary objective in formulation of DVC, the Central Government, in consultation with the state governments concerned (erstwhile Bihar and West Bengal) worked out a unified development project for the Damodar Basin. The Damodar Flood Enquiry Committee suggested a comprehensive plan. Following several reviews and consultations with all concerned, a Multipurpose River Valley Project under Damodar Valley Corporation (DVC) was initiated by the Government of India for the entire basin in 1948. Known as Damodar Valley Project, four dams viz. Tilaiya, Konar, Maithon and Panchet Hill dam were conceived and constructed in the upper valley besides a barrage downstream at Durgapur in the middle valley segment that can help irrigated agricultural water diversions. The Damodar valley and the location of the four dam projects is shown in figure.

Tilaiya Dam

Tilaiya dam, constructed on Barakar River, was started in 1950 and got completed by 1953 itself. With a dam top length of 366 metres the dam has a maximum height above the river bed of 30 metres. Its gross storage capacity is 395 million cubic metres and its live storage capacity is 321 million cubic metres. Two power stations of 2000 K.W. each also formed part of the Plan.

Konar Dam

Konar dam, constructed on Konar River (in Hazaribagh district now in Jharkhand) is 3349 metres long with a maximum height above river bed of 49 metres. It is an earthen dam with a concrete spillway. Its gross storage capacity is 337 million cubic metres and live storage capacity is 276 million cubic metres. Construction on this dam started in 1950 and it was completed in 1955. It has an installed capacity of 10 MW. Bokaro steel plant and Bokaro thermal plant receive hydroelectric power and clean water, respectively from this dam. The scheme has an irrigation potential of 45,000 hectares.

Maithon Dam

Fig Perspective view of Maithon dam

Maithon dam is located on the Barakar River about 12.9 km above its confluence with the Damodar River on the border of Dhanbad and Burdwan districts of Jharkhand and West Bengal respectively. This dam and the Panchet Hill dam are operated for flood control, supplying irrigation water and power generation. The dam is a composite structure of concrete and earth.

The spillway has been provided with 12.2 m high x 12.5 m wide tainter type crest gates for flood control purpose. Besides these spill bays, five under sluices, each of size 3.1 m high x 1.7 m wide have been provided in the body of the spillway for controlling the flow at lower level. The perspective view of the dam is shown in Figure.

Maithon Power Station has an underground Power House of 63.20 MW in the left bank, a first of its kind in India at the time when it was built. (2x21 MW - 1x23.4 MW)

Panchet Hill Dam

Fig. : Perspective view of Panchet Hill dam

Panchet Hill dam is located on the Damodar river near Asansol on the border of Jharkhand and West Bengal and is about 4.8 km above the confluence with the Barakar river. This dam along with the Maithon dam is operated for flood control, supplying irrigation water in the lower valley and also for power generation. The construction of the dam was completed in 1959.This dam is a composite dam of concrete with zoned filled earthen embankments on the left and right side of the concrete structure. Two saddle dykes, one at each extreme end of the earth embankments form part of the complex. The perspective plan of the dam is seen in Figure.

Panchet Hill dam provides hydroelectricity of 80 MW (2 units of 40 MW) and has an over ground power house.

• Peninsular India

In the peninsular India there were many impressive water resources development projects that took place in the later half of the last century.

• Tungabhadra Project

Tungabhadra dam is constructed across the Tungabhadra River, a tributary of the Krishna River. The dam is located near the town of Hospet in Karnataka. This was a joint project of erstwhile Princely state of Hyderabad state and erstwhile Madras Presidency when the construction was started but later it became joint project of Karnataka and Andhra Pradesh after its completion in the year 1953.

A little history on this project brings to light the role of engineers in earlier times, around the inception years of IEI. The endemic famine region of Rayalseema, comprising the districts of Bellary, Anantapur, Kurnool and Cuddapah attracted the attention of the British Engineers as early as 1860. To relieve the intensity of famine in these districts, proposals were made in 1860 to utilize the waters of Tungabhadra through a storage reservoir and a system of canals to provide irrigation for the lands.

Sir Arthur Cotton originally conceived the Tungabhadra Project in the year 1860. The proposals were further modified and developed subsequently evolving it into a joint scheme with Hyderabad. The then Govt. of Madras in 1940 ordered for the detailed investigation of the scheme based on the agreements concluded and examination of a number of alternatives. The Agreement between Madras and Hyderabad of June 1944 enabled the Madras and Hyderabad Governments finally to start the construction of the Tungabhadra project. The Tungabhadra Project was formally inaugurated by laying foundation stone on 28th February, 1945. However, much headway could not be made up till January 1949. Difference of opinion in certain technical matters and unsettled political situation in Hyderabad were the reasons for the slow progress. Excavation in the riverbed was started in 1947 and masonry construction on the 15th April 1949. With help of a cofferdam constructed earlier, foundation excavation was continued during flood season also. The river bed portion was tackled during the summer of 1950 (1949-50). Masonry in the riverbed blocks was started in the year 1951. Thereafter there was vigorous progress in works. By October 1953 the structures were completed substantially enabling the storage of water in the reservoir up to +492m. The balance of the works namely the spillway, bridge road on the top of the dam, construction of utility tower, manufacture of crest grates for storing water up to 1633 level were completed in all respects by the end of June 1958. The water was led down into the canal on the 1st of July 1953 to derive partial benefits.

Hydroelectric Scheme: The Tungabhadra Hydroelectric Scheme was undertaken in the composite Madras State in the post war period under the first five-year plan in the year 1950. The work on the project was taken up in the year 1951 but no appreciable progress was achieved till the end of the year 1953. During 1957 two units of 9 MW each at Dam Power House were installed and in 1958 two units of 9MW each were installed at Hampi Power House. Thus the first stage of the scheme was completed in 1958 and the second stage under this scheme was taken up in the year 1959. The plant erection was started in the Dam Power House in November 1962 and in the Hampi Power House in February 1963. Under stage II the units 3 and 4 of both, Dam Power House and Hampi Power House started functioning by June 1964.

This project is now a joint undertaking of the Governments of Karnataka and Andhra Pradesh to harness the river water for irrigation, power generation, flood control and drought mitigation. The dam is a 2440 m long and 49.38 m high Gravity Stone Masonry dam.

Three power houses of installed capacity of 126 MW have been constructed under the project.

Three canal systems originate from the Tungabhadra Barrage: The Left Bank Canal is 340 km long and irrigates about 3.32 lakh hectares; Tungabhadra Low Level Canal originates from the right side of the dam. It is 347 km long and irrigates about 60,000 Ha; Tungabhadra High Level Canal with 196 km length provides irrigation to 1.82 lakh hectares.

• Hirakud Multipurpose Project

Hirakud dam is the first post-Independence major multipurpose project in India built across Mahanadi River in the State of Odisha. Mahanadi drains total area of 1,41,600 sq km, mostly of Madhya Pradesh, Chhattisgarh and Odisha, before discharging to Bay of Bengal. Devastating floods in its lower deltaic plains in coastal districts were a recurring phenomenon earlier times. Hence, the Hirakud reservoir across Mahanadi was conceived primarily for flood control of Mahanadi delta. Also, the lands in the old district of Sambalpur and Bolangir (Presently Bargarh, Sambalpur, Subarnapur and Bolangir) western Odisha were often facing draught situation due to erratic rainfall pattern, even though this mighty river was flowing through these districts and regulated irrigation was possible only when a storage dam is built across the river.

After the high flood of 1937, Sir M. Visveswaraya planted seeds for Mahanadi development. The flood Advisory Committee (1938-42) of British India Government recommended construction of a multipurpose reservoir in Mahanadi Basin. Alongside, potentialities of river Mahanadi for a multipurpose i.e. flood control, irrigation, navigation and power generation development stood recognised. The survey and investigation were accordingly undertaken by Central Water Ways Investigation and Navigation Commission (later on named as Central Water and Power

Commission). The foundation stone of Hirakud dam was laid by Sri Hawthorne Lewis, the Governor of Orissa on 15th March, 1946. The first batch of concrete was laid by Prime Minister of India, Shri Jawaharlal Nehru on 12th April 1948 and later he again had the privilege of its inauguration in January 1957. The first filling of the reservoir started during the year 1956 and power generation, along with water supply for irrigation started from the year 1956. Full potential was achieved by 1966.

• Hirakud Dam

Hirakud dam is a composite structure of earth, concrete and masonry built across river Mahanadi. The main dam having an overall length of 4.8 km spans between abutment hills. The dam is flanked by earthen dykes 21 km long on both left and right sides to close the low saddles beyond the abutment hills. The right dyke is 10759 m long in one stretch whereas the left dykes are 9837 m long laid in five gaps. The dam principally blocked two arms of river Mahanadi, the left 600 m and right 750 m by concrete spillways.

Figure: Perspective view of Hirakud dam

The length of main right earth dam and left spillway dam is 2298.2 m, whereas the length of earth dam between left spillway dam and left abutment hill is 1353.3 m.

The spillways are solid gravity dams with ogee shaped crest. Both the spillways contain 64 nos. under sluices 40 nos. in the left and 24 nos. in the right with floor at RL. 154.43 m. Each sluice has width of 3.658 m and height 6.08 m. Vertical shafts 1.42 m x 5.08 m connect the sluice barrels with an operation gallery at RL. 168.66 m. The sluice gates are operated from the operation gallery of size 3.35 m x 7.01 m by overhead travelling cranes and lifting beams. There are 34 nos. of radial crest gates, 21 nos. in the left spillway and 13 nos. in the right spillway of size 15.54 m x 6.10 m each. The spillway capacity is 42,450 cumecs.

The power house of 307.50 MW capacity is located in the right flank as downstream toe power house of non-overflow blocks. Full supply discharge from power house-I at Burla is 990.50 cumecs which is carried through a power channel.

• Koyna Project

The Koyna Project took shape mainly as a result of the increasing requirements of power of the highly industrialized city of Bombay and its environs. This region was experiencing an acute shortage of power with its phenomenal growth after the Second World War as India’s business capital. Koyna Hydroelectric Project Stage I Power House scheme was administratively approved by Government in 1953. The scheme also provided for irrigation storage for serving irrigation on the dams of Koyna and Krishna rivers upto the State boundary. Koyna dam is constructed across River Koyna. The Koyna HE project, of which Koyna dam forms an important component, is composed of four dams. The Koyna Dam and Koldewadi Dam are two major dams of this Koyna Hydroelectric Project in Western Ghats. Koyna dam is 103.02 m high above deepest foundation with a total length of 805 m.

Figure: Perspective view of Koyna dam

The type of construction used for the main dam is unique, in that it uses rubble concrete, i.e. rubble sunk in concrete by vibration. Unique in its own manner, Koyna dam is a sort of mechanized masonry or so called ‘rubble concrete dam’ (in the lines of such dams constructed elsewhere like the dam on Ocker River in Germany). The dam impounds a reservoir with a gross storage capacity of 2.80 km^3. The spillway is centrally located and has six radial gates each 12.5 m x 6.2m. A sluice with emergency and service gates are provided centrally in the spillway portion to let down irrigation discharges.

The power generation is through a network of power stations called Koyna I & II, Koyna III & IV.

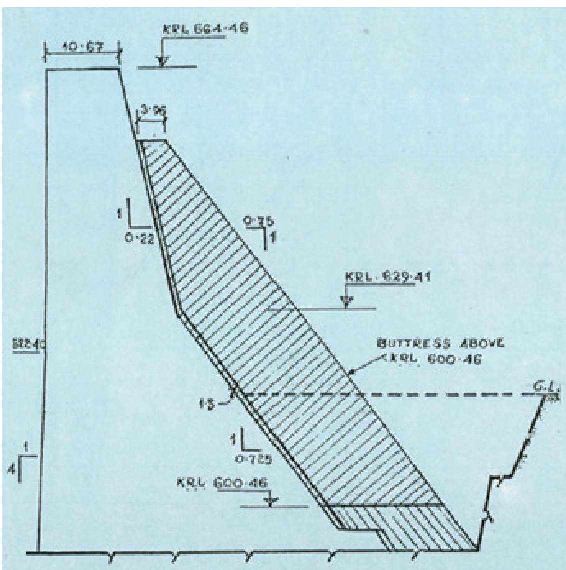


Figure: Section of Strengthened Koyna Dam after 1967 Earthquake

The entire Koyna region suffered an unprecedented earthquake of severe intensity of magnitude 6.3 (Richter scale) on December 11, 1967. Because of this, Koyna dam and appurtenant structures suffered some damages like cracking of the dam near the top neck. The aseismic design aspects of a dam needed a review besides even the way one goes about determining the seismic parameters for consideration in designs of dams. Very simplistic assumptions were in vogue prior to the present day seismic codes were brought in for designers and the dam was found to be inadequately designed to withstand the seismic shaking of higher order which had visited the region for the first time then.

At the time when Koyna dam was designed a simplistic horizontal uniform acceleration was assumed to act upon the structure. This assumption had to be reviewed in the light of advancement of knowledge about designing dams to withstand seismic forces. The dam was then strengthened by 'concrete backing' or buttress wall from down-stream side, properly key to the main structure. As seen in the typical cross-section of strengthened Koyna dam, rehabilitation measures to address the damages suffered due to earthquakes, started in '70s. Koyna's case stood as reference globally for the review of seismic design parameters besides the philosophy of Reservoir Induced Seismicity (RIS); besides, certain design provisions in accommodating forces due to seismicity emerged in Indian dam designs procedures. Bringing in Advanced numerical analysis using FEM technologies in subsequent decades had taken strides including considerations in the assumption of Material Characterization for dynamic analysis.

• Nagarjunsagar Project

Meant to harness the River Krishna in Andha Pradesh State to cater to water supply, Nagarjunasagar dam is of a maximum height of 124.66 m above the deepest foundation level. It has a significant mass and the total volume of masonry dam is about 5.61 million cubic meters. This dam thus retains the privilege of being the highest and largest rubble masonry dam in the world built by only a huge input of manual labour, ever engaged on the construction of any dam in the world. The maximum labour personnel engaged was of the order of 60,000 ; it stood as an example of those days where 'men vs machinery' was one of the typical discussion point in the development agenda of a emerging economy where surplus labour was available at negligible opportunity cost . India was facing a very severe resource crunch coupled with a challenge of providing job opportunity to many who were not skilled enough. Engaging the idle labour was given overriding consideration than the use of machinery for the huge construction activity.

The reservoir with a water spread area of 285 sq km and a gross storage capacity of 1.156 million

Ha m is considered again as one of the largest man-made lakes in the world. There are two canals taking off from the reservoir at either flank with maximum discharging capacities of 595 and 425 cumecs to irrigate lands.

Figure: Perspective view of Nagarjunasagar dam

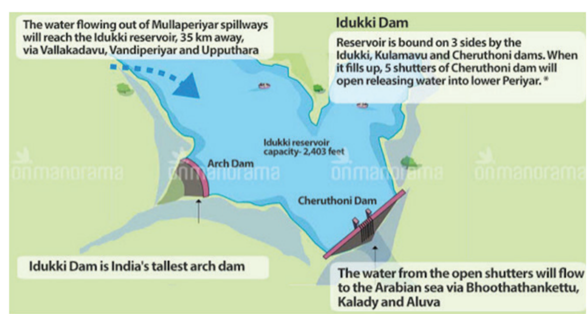
The entire dam section, excluding the spillway crest, glacis and bucket and areas around the galleries, sluices and other openings in the dam, was built in rubble masonry in cement-surkhi mortar. The main dam is flanked by earthen dam to a length of 2,560 m on the left flank and 853 m on the right flank, rising to a maximum height of 25.9 m above the stripped ground.

The non-over flow section of dam extends to a length of 425.8 m on the left flank and 552.91m on the right flank of the spillway dam. Eight penstocks of 4.88 m diameter are embedded in the left non-overflow dam for purposes of power development. A central spillway portion of the masonry dam is 470.92 m in length, with crest at + 166.42 m as against the top of dam of +184.40 m, fitted with 26 radial gates of size 13.72 m x 13.41 m, is capable of discharging 37,240 cumecs at the FRL of +179.83 m and 43,320 cumecs at the MWI of + 181.05 m. Besides, two chute sluices of size 3.05 m x 7.62 m are also provided in the non-over flow section of the dam, one at either end of the spillway dam, for supplying water to Krishna delta in times of need.

Nine vents of size 3.05 m x 4.57 m are provided in the right non-over flow dam forming the head sluice for the right canal, with 3 power sluices of size 4.57 m x 11.58 m adjacent, for power development on the right bank. The left canal, however, takes off from the foreshore of the reservoir through a head sluice provided in a separate low dam formed across a local valley. A diversion-cum-irrigation tunnel of 8.23 m diameter was bored through the hill on the left flank to a length of 789.43 m for diversion of summer flows of the river during construction of dam and for supplying waters to Krishna delta lower down when required.

• Idukki Project

Idukki dam is the first dam constructed in double curvature arch type in Asia. The Idukki Arch Dam across Periyar River is part of the complex of Hydroelectric Project that has an installed capacity of 780 MW. The dam of 161.9 m high was constructed between 1969 and 1974. The reservoir behind is in fact created by a set of three dams, namely (i) the Idukki dam constructed across the River Periyar (ii) a concrete gravity dam across the River Cheruthoni and (iii) a masonry dam across a saddle at Kulamavu. A schematic plan showing Idukki & Cheruthoni dam and the impounded reservoir is shown in figure below.



Idukki project is unique in many respects. Idukki is the biggest hydroelectric project in the State of Kerala. The power house is the largest underground power station in India. The tail race discharge is used for irrigation of about 60,000 Ha in Muvattapuzha basin. SNC-LAVALIN INC. under contract with the Canadian International Development Agency (CIDA), assisted the Government of India and the Kerala State Electricity Board (KSEB) in the design, construction and subsequent monitoring of the Idukki Dam.

Idukki Dam

The Idukki Arch dam, straddles a steep V-shaped gorge eroded by the Periyar River through massive charnockite rocks. It is a non-overflow, double curvature, parabolic, thin asymmetrical arch dam. The maximum height above the lowest point of foundation is 169.16 m. The arch dam is made up of 24 individual blocks with a crest length of 381m3, a crest width of 7.6 m and a maximum base width of 24.4 m. The volume of concrete utilised for its construction amounted to 469000 m^3. There are three levels of horizontal inspection galleries through the interior of the dam and all extends a minimum of 85 m into the foundation on both sides of the canyon. The horizontally formed galleries are interconnected to an inclined, formed foot gallery following the rock-concrete interface from one abutment to the other. The perspective view and downstream elevation of Idukki dam are shown in figures below.

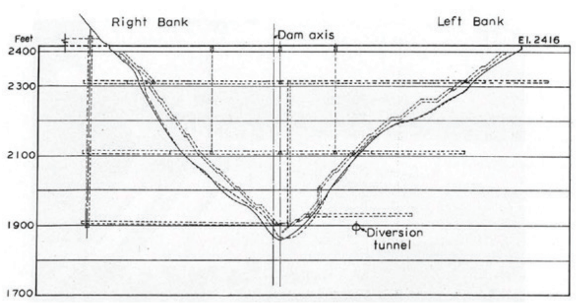


Fig. : Perspective view of Idukki dam (left) and downstream elevation above)

Other Impressive WRD Projects

While the list of achievements of large dams and water diversions is too long to get covered fully, some mention of a few notable ones at least as headlines may be interesting.

(i) Sri Rama Sagar or Pochampad Project (now in Telengana) – Earth cum Masonry Dam 43m height, 15,600 m long Multi-purpose Project

(ii) Mahi Bajaj Sagar Project (Rajasthan) 74 m high, 10 m long dam (Earthen and Masonry) Multipurpose Project

(iii) Totladoh (Pench Hydel) Project Maharashtra

(iv) Ranjit Sagar Dam Punjab Dama cross Ravi River, in Jammu Kashmir

(v) Baglihar Dam – Dam across Chenab in J&K

(vi) Sala HEP (J&K).

More details of each one of them may be resourced from other sources as a description of each one of them might seek few more pages for this paper.

IMPRESSIVE WORLD CLASS WRD PROJECTS THAT WERE BROUGHT INTO OPERATION IN THE RECENT DECADES – ONE TYPICAL ILLUSTRATION OF TEHRI DAM

The author would like to place on record a few of the recent engineering marvels that the Indian engineering community could bring in. These are fairly impressive and unique even by current universal standards and had received accolade from International Organisations like ICOLD in recent times. These dams enabled significant high innovative solutions in difficult design backgrounds given geological and other complications of the locations in which they were situated. India could bring in almost all the largest of their kinds, like highest embankment dam in seismic environs, largest storage categories and hydroelectric projects with many unique features like the largest underground desilting complex, the longest and largest Head Race Tunnel and deepest Surge Shaft in the World. Nathpa Jhakhri Hydro electric project stands is a typical one, a runoff river diversion dam and hydro electric generation with longest tunnelling in difficult geological settings and consequent challenges.

At least one of the projects of significance may be allowed to glimpse its highlights even when there is some restriction in space; given the desirability of limiting the chapter on 'water resources in the current work of IEI in its centenary volume, this one case, i.e., the Tehri Dam in Himalayas is being illustrated; the engineering marvels that one could find in this world class dam of the 20th century built with indigenous strength (Atma Nirbhar Bharat) may enable the Indian Engineering strength to be appropriately brought out. Besides, a briefer coverage on Saradar Sarovar Project across Narmada River is attempted in this article.

Tehri Dam

A lead engineering marvels of the past few decades in high dam in Himalayas that the country could proudly project is the highest embankment dam of 262 m height across River Bhagirathi especially in a 'high seismic proneness setting'. Admirable engineering aspects include:

- The Design of the Fill Dam section to withstand severe seismic shaking (Richter Magnitude +8) with special zoning features incorporates a gallery in the fill at mid level in the clay core section (besides an additional one also at the top - just below the road); such galleries are unusual features in the body of embankment dams;
- Flood handling system that encompassed the flood handling operation sequenced three different types of spilling arrangements. Apart from a chute spillway in the abutments to the extent that the topography could allow, for handling the additional flood discharge, one gated shaft spillway and another morning glory type of vertical shaft spillway, crest at full reservoir level (FRL) were incorporated. These are being called upon to serve only when excess floods are encountered. The morning glory spill would come into operation only when the reservoir level exceeds FRL. The shaft spillway having a record fall depth of nearly 230 m, is the highest fall structure of its kind, around the world.
- Unique energy dissipation arrangements by swivelling action to kill the energy. The high velocity flows at the bottom of the vertical shaft spillway are turned into swirl flow in the horizontal tunnels leading the discharge in to the river downstream; the provision of sufficient de-aeration arrangements by special aeration tunnels accessed from downstream is somewhat unique of their kind. And last but not the least,
- Caverns for locating machine halls and transformers with intakes on a geologically challenging slopes needing extra ordinary strengthening arrangements in each case; special instrumentation stood incorporated to facilitate performance monitoring of the cavern behaviour.

The 260.5 m high earth & rockfill dam has been designed adopting standard design practices. The average u/s and d/s slopes of dam are 2.5 H: 1V and 2.0 H: 1V respectively and this has been conservatively adopted. A freeboard of 9.5m above full reservoir level (FRL), precludes the rarest possibility of any overtopping and consequential disaster apprehensions. The crest of dam is 25.5 m wide in the central portion, flaring to 30.5 m near abutments. The dam section is composed of a central impervious core, transition zones on both u/s and d/s of core (filter zones), pervious shell zones and the protection with random stone riprap of sufficient size ensures no disturbance with wave run up under high wind velocities even when the reservoir is full. The final dam section as adopted varies from section to section along the axis as dictated by topography of the canyon as well as a curvaceous river reach that helped stability against some apprehensions of sliding from its location. The idealized general section for an easier understanding is shown beneath:

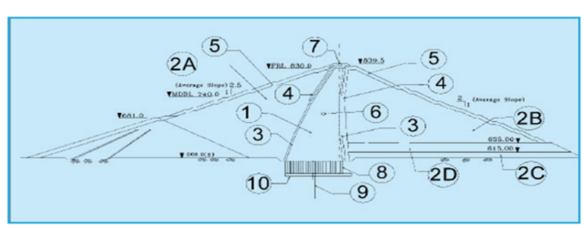


Figure: Typical Section of Tehri Dam

Index:

(1) Impervious Core

(2A) Upstream Shell (2B) Downstream Shell (2C) Processed Shell (2D) Processed Shell

(3) Fine Filter

(4) Coarse Filter

(5) Riprap

(6) Inspection Gallery at El. 725 m (+/-)

(7) Inspection Gallery at El. 835 m (+/-)

(8) Consolidation Grouting (9) Grout Curtain (10) Underground Grouting Gallery

Inspection Galleries in the body of dam

A novel feature of dam design is the provision of two inspection galleries in the body of dam one in the dam core at El. 725.0 m along center line of core, with 2.2 m finished diameter and another close to the top at El. 838.0 with base open to facilitate visual inspection of the top fill material; This is rectangular and is of dimensions 2.5 m x 2.4 m. The provision of such galleries in the impervious clay core portion in fill dams is a rarity for obvious reasons. These are uncommon in western practices normally. However some examples do exist like the one in Nurek (former USSR, now in Tajikstan), Charvak dam in present Uzbekistan, and the High Aswan dam in Egypt. Save the Russian practice of providing such galleries, one obtain this practice nowhere else; and the Indian Designers accepted the initial suggestions of the Russians in adopting this unique feature by detailing the design for construction. The gallery helps to study the health of the dam and observations to date confirm normal behavior based on functional instrumentation readings.

The mid level core gallery at El. 725.0 would enable continually a direct visual inspection in future also; nevertheless, the monitoring of horizontal and vertical in clay core during construction and operation period helped engineers and the technical advisory committee members inferences to confirm the expected behavior. The middle level core (El. 725+) gallery is home for all the junction boxes and cables, coming from all the instruments installed in the core below the level of Inspection gallery as well as abutments. Of significance is the possibility of capturing strong motions during severe earthquakes with instruments placed for the purpose in this gallery, a feature that help back analysis on the behavior of the dam during severe earthquakes whenever seismic events take place ; should an event of significance occurs, Tehri High Dam can provide data for understanding the behavior of high dams in narrow canyons, the variations in acceleration along the canyon like mid dam, foundation and top of the dam etc; it also facilitate the verification of performance by back analysis. And, and if so required, such post earthquake remedial measures as is obligatory can also be planned and executed during the entire period of the project servicing the humanity.

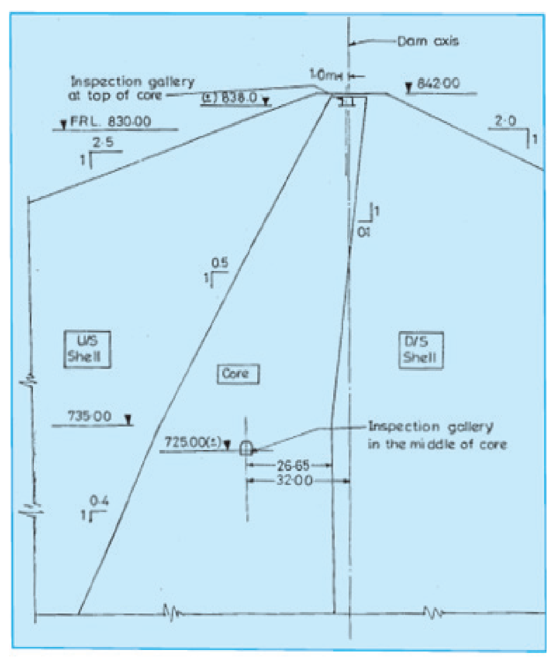


Figure: Mid-level Inspection gallery & Top Level Inspection Gallery in Dam Section

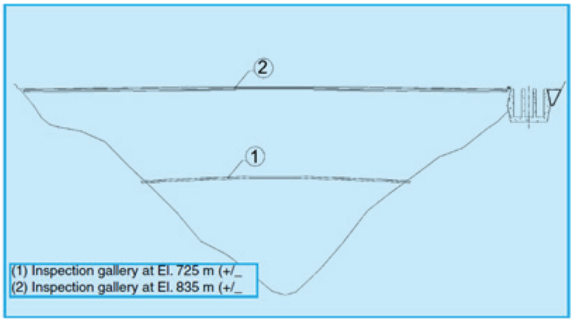


Figure: Longitudinal Section showing the Upper and middle level galleries in the core portion

The top gallery at El. 838 m is located just beneath the road and is expected to help direct and continuous visual examination of core surface at the top of dam. The detecting of cracks, if any, in the monitoring phase will always be easier avoiding notional inferences. This would be relevant in the reaches close to abutments, at the dam top, due to tensile stresses induced by differential settlement. Past Studies done elsewhere indicate that manifestation of tensile stresses could be more pronounced in about 1/5th of the dam length at top near the abutments, along the longitudinal axis of the dam, perpendicular to the flow direction. While provision has been made in the design and construction for taking care of any such manifestation, visual observation through this gallery would provide further confidence.

Handling of Probable Maximum Flood (PMF) in Bhagirathi River

The estimated probable maximum flood PMF at Tehri site is 15540 cumecs. In order to safely evacuate the large flood in a narrow canyon that provided insufficient width for the chute spillway, a battery of varying solution or types were embedded in the layout, namely, two shaft spills in each one of the flanks (left and right) besides the main gated chute spillway in the extreme right flank of the canyon. The routed flood discharge for the scheme of spillway structures, remain around 13,000 cumecs with a flood lift of 5.0 m above FRL. While the occurrence of PMF would be an extremely rare event, the system for flood evacuation would be getting sequentially ordered keeping in view all relevant aspects in the particular year for events of lesser levels like Standard Project Flood. Only about 50% of the evacuation is by chute spillway is envisaged, sequentially first in operation. Given the energy levels at the floor at bottom which are substantially high and of the order of MW, special care had to be bestowed in the chute design. Amongst other measures, introducing aerators at two intermediate levels had been incorporated. Besides special care to design the chute and the stilling basin with High Performance Concrete that can resist abrasion and strengthening of the stilling basin floor with deep anchors etc, are executed. What is of significance is that the stilling basin floor itself crosses in foundation a faulted and sheared reach asking for additional special treatment. The stilling basin for the chute is designed and dimensioned for a lesser than PMF level discharge. This implies that in the extremely rare incidence of PMF, some damages in the stilling basin could be expected.

Figure: A perspective view of Chute Spillway with three Crest Gates, located on the right bank hill slopes (in deep cut sections, to found them on competent fresh rock and also to satisfy the desired hydraulics for ensuring smoother transitions)

This preference is due to techno economic advantages and a superior performance for all normally visualized discharges. The cost of repairs in the lifetime of the reservoir when PMF or near PMF types of floods occur is expected to be less than the incremental cost involved in designing the basin itself safe for maximum probable flood. The structural design of basin is adequate enough to resist dynamic pressures generated during operation. The entire arrangements had proven its ability to handle large floods as envisaged safely, when a severe flood in 2014 was quite well handled by the available provisions made in the dam thus proving the protype behaving as envisaged in earlier hydraulic model studies prior to dam construction.

The layout of the Project is depicted in Figure:

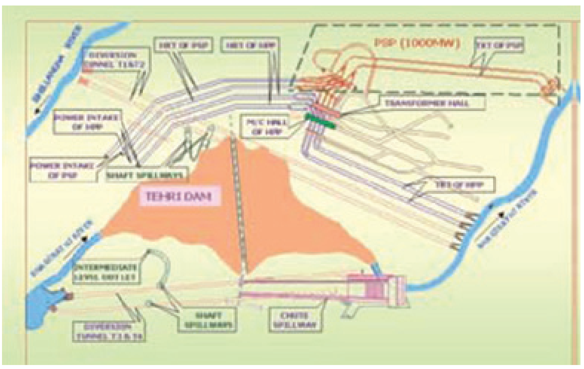


Figure: Depiction of Project layout

The shaft spillways, two in the right flank are gated spillways. They envisage several specific components and well-designed transitions from inlet to outlet including the fall in the shaft by nearly 200 m. The designs were subjected to rigorous model testing for its sufficiency. The hydraulic model studies were undertaken in the Central Water and Power Research Station, Pune as well as UP Irrigation Research Institute, Roorkee before confirming different features embedded in the system for execution.

Energy Dissipation arrangements for the flows handled by the Shaft (>230 m. fall) Spillway

The chute spillway as designed and implemented above had the following arrangements as shown in the Section, depicting also the horizontal stilling basin arrangements downstream.

The features for the shaft spillways included the Vortex prevention with pier shapes conducive for the purpose; the deep and vertical shaft was provided with arrangements for aeration, at specific locations. At the bottom where the vertical shaft meets the horizontal tunnel to convey the water downstream, a swirling device was specially incorporated to cause a rotational swirling action. This can progressively reduce the forces by frictional losses and thereby achieve reduction of velocity as the water gets conveyed along the downstream tail race. This portion also has special de-aeration system to cope up with air demand, as required.

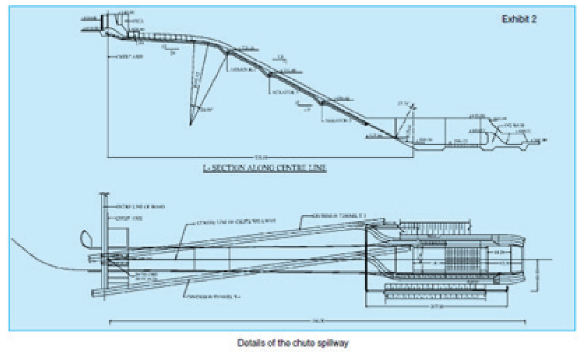


Figure: Tehri Chute Spillway – Section showing aeration arrangements and stilling basin on faulty foundation with special provisions

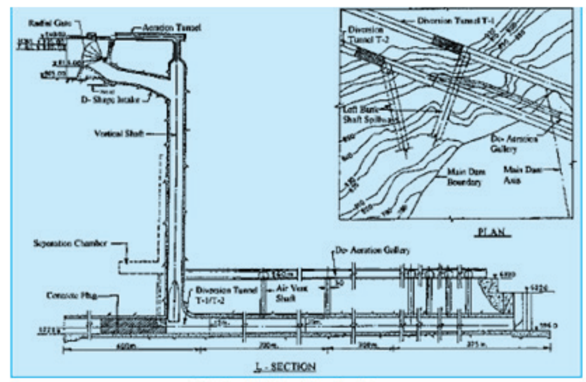
The intake of the shaft spillways is a funnel shaped structure with uncontrolled circular weir of 34.0 m diameter, with the crest at EL. 830.20 m. The discharge capacity of each shaft spillway is limited to the maximum design flow to be passed by each diversion tunnel during construction period. The dimensions of the crest have been fixed up so as to pass this discharge of 1925 cumecs at reservoir level of El 835.0 m., attained during PMF. A concrete pier is provided on the hill side of the intake to contain the spin motion of the water when it flows over the crest and falls into the vertical shaft. The shape of the crest profile is designed in a way such that the negative pressure does not develop over the entire range of flow to be passed through the shaft spillways.

What is special in the design of Tehri shaft spillage system lies in the fact that the vertical shaft joins eccentrically with the tailrace tunnel through a swirling motion to achieve intensive dissipation of the flow energy. In the system adopted for Tehri Dam Spillways, the center line of the shaft is positioned at an eccentricity of 6 m from the tunnel centre line in horizontal plane. Apart from this, the section of the shaft is also reduced on the two sides resulting in a typical section comprising of radial and plane surfaces.

The horse-shoe section of the earlier diversion tunnel was converted into 12 m dia circular section to facilitate and to preserve the induced swirling motion to a longer reach. The circular section of 12 m dia was modified by converting the earlier horseshoe diversion tunnel section of 11.0 m in a 10 m length transition. On the upstream side of the junction of shaft with tunnel, a concrete plug constructed in a length of 45 m. closed the earlier entry arrangements for water in the diversion tunnel that got modified to serve as permanent evacuation arrangement component in the shaft spillways.

The shaft spillways were called into operation during the severe 2011 floods and had demonstrated its serviceability. So is the case with the chute spillway. The reservoir level rose during the floods to almost El. 835 which is MWL. It was observed as anticipated that the air entrainment in large quantities remained as a particular feature of the functioning of the shaft spillways. The flow entering into the shaft spillway was sufficiently aerated at the top. It did carry a lot of air along with discharge reduction and lowering of the crotch with deeper fall with increased velocities in the vertical shaft. The air entrained gets initially compressed and then expands at the junction apparently; and hence, the threat of exerting very high instantaneous and dynamic pressures on the lining as well as the shaft and 'contact rocks' did mean and the high strength concrete as designed served to counter the resultant effects, well.

When the swirling flow is induced in the horizontal tail race water conductor tunnel, the air gets accumulated in the central core in the form of air-vapour mixture. This could be a concern and need a special attention by post observation and remedial steps. The swirling flow caused apparently a gradual subsidence on the downstream side as it progressed, as envisaged. The earlier model tests indicated that the air entrained in the core slowly starts coming up in the form of discrete air bubbles. As the travel of these bubbles along the tunnel and their escape at the outlets induce large pressure pulsations and hence large negative and positive stresses on the tunnel lining, the design specified high performance concrete M50 with Micro Silica fume, as required as per a special mix design.



Details of left bank shaft spillways

Figure: Details of left bank shaft spillways

The de-aeration system provided to reduce the negative effects of dynamic loading on the lining also served its purpose in the prototype when the system was obliged to handle the severe floods during the 2011 monsoon season. Air from the core formed at the junction of the shaft and the tunnel was getting extracted through 'de-aeration system'; apparently, maximum amount of air entrapped in the core of the spinning flow could be safely handled without many damages. Some detail of the de-aeration arrangements in the system is worth mention. The de-aeration system in the water conductor consists of an air pipeline to remove vapour air mix, another pipe to remove separated water, a separation chamber and an air duct opening to atmosphere for expelling the air out from separation chamber. Elaborate hydraulic model studies carried out at the Scientific Research Centre, Moscow as well as Irrigation Research Institute, Roorkee formed the basis for this arrangement. The dimensions of various elements of the de-aeration system incorporated in the final design comprise of an air-vapour discharge pipe of 3.0 m diameter, separated water pipe of 1.5 m and a separation chamber of size 24 m x 08 m x 06 m. The air vent of the D-Section executed to house the facilities was having a sectional area of 16.0 m^2.

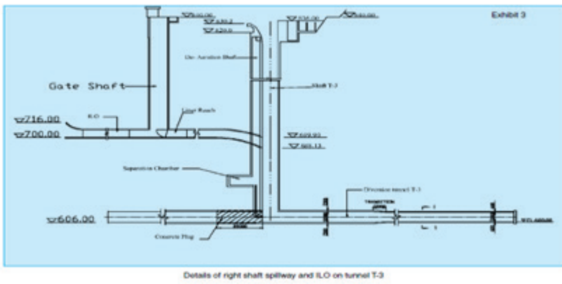


Figure: Left Bank Gated Shaft Spillways

The right bank shaft spillway is an ungated morning glory type of a record depth fall. Of significance is the combination of this facility with a planned intermediate level irrigation release outlet. The later is meant take on board such necessities like the need to assure irrigation releases, even when power generation halts, for whatsoever reasons. The assured release of water for downstream irrigation was to assure all downstream demands of the riparian States for irrigation, societal requirements like Maha Khumbh mela Snans (holy dip in the river Gabges) besides other environmental requirements. The principles of the right flank shaft spillway is akin to and comparable with that of the left bank shaft spillways; and, all the special measures mentioned for the energy dissipation like eccentric let in from vertical shaft to horizontal duct for ensuring the spiraling flow etc apply to this spillway also.

Figure depicts the Right Bank Morning Glory Shaft Spillways (ungated) with top at FRL El. 830.00 and the section indicates right Bank morning glory spillway showing Intermediate Level Irrigation Outlet

The intermediate level outlet system gets coupled with the morning glory spill shaft at some middle level. This gets juxtaposed in a hydraulically efficient manner with the other arrangements for flood discharge handling system through the shaft spillway structure. This is a unique site-specific solution and claims to have no parallel. This is displayed in the section. The high head control gates of radial type placed in an exclusive shaft to handle the same with an emergency gate upstream asked for several challenges particularly because the ledge rock in which these facilities were positioned itself needed a lot of strengthening measures. Coupled were the various issues relating to assure safe operational needs. The gates have been tested and some additional strengthening of the mass rock behind the lining are post construction measure with further monitoring arrangements.

Large Caverns in a Complex geological environment

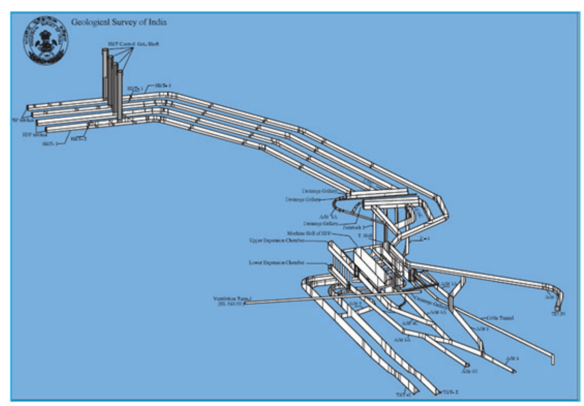


Figure: The model perspective projection of the entire power house

The geotechnical assessment in the earlier stages helped the determination of appropriate locations for the large size underground rock cavities for both the machine hall as well as transformer hall, running parallel to each other. The best competent strata (Grade-I) was identified as to be the one at right flank hills. The orientation of the cavities was favorable (against the dip direction) in this choice location. The machine hall cavern (197 m x 67 m x 24 m) is aligned in N20°E. The transformer hall and expansion chambers are located in the upstream are aligned parallel to the machine hall. The rock cover available above the roof of the machine hall cavern is about 350 m. The crown of the cavity is at El 630.2 m and the bottom most portions are at El. 563 m. The geological setting in the cavern locations are somewhat similar to those observed in the canyon in which the dam is founded. The same inter-bedded sequence of phyllitic quartzite massive (PQM) and phyllitic quartzite thinly bedded (PQT) and occasional bands of quartzitic phyllite (QP) was discernible in the underground cavern excavation sites. The sheared/ shattered phyllite (SP) occupies the affected zones/ tectonised zones along the major shear planes in the machine hall cavern. The primary bedding joints were dipping at 42°- 55°/ N195-235 and were cut across by the foliation planes dipping at 38°-44°/N160-210. The variation in the attitudes of the beds was due to folding pattern and was prominent between RDs 51.0 m and 95.0 m, on the left half of the cavity. The system of underground works that were forming part of the Underground Power House Complex is seen in the perspective view seen in figure (GSI): The perspective projection in the model of the entire power house complex illustrates the intricacies associated with planning, design and execution of this mighty complex in a challenging Himalayan geotechnical environ.

Sardar Sarovar Dam

Four Indian states, Gujarat, Madhya Pradesh, Maharashtra and Rajasthan, receive water and electricity supplied from the reservoir created by the impressive Sardar Sarovar Dam in India, a project of world class importance since it attracted various reviews during its long gestation period of inception followed by construction over several decades. In 1979, seeds were sown for the initiation of the multipurpose development of Narmada River for associated irrigated agricultural development and hydroelectric power besides water supply for industry, drinking water and environment enhancement. The construction of Sardar Sarovar Dam commenced in 1987, but the project was stalled by the litigation from time to time but could see its completion in recent times. One of the 30 dams planned on river Narmada, Sardar Sarovar Dam (SSD) is the largest structure to be built. Sardar Sarovar Dam is the second largest concrete dam in the world in terms of the volume of concrete used to construct dam after the Grand Coulee dam across River Columbia, US. It is a part of the Narmada Valley Project, a large hydraulic engineering project involving the construction of a series of large irrigation and hydroelectric multi-purpose dams on the Narmada River. The project will support irrigated agricultural development in more than 18,000 km^2 (6,900 sq mi), most of it covering drought prone areas of Gujarat State in Kutch and Saurashtra.

The main dam consists of 23 bays of service spillways of size 18.30 m x 16.76 m high and 7 bays of auxiliary spillway of size 18.30 m x 18.30 m high to pass about 90,100 m^3/sec at MWL El. 140.21m. Thus, of the total length of 1210 m of main dam, the central 750 m river portion is covered by gated spillway sections to pass the floods. The remaining 460 m on either flank comprise non-overflow sections. The service spillway has a sloping cum horizontal stilling basin type energy dissipator and the auxiliary spillway has a chute terminating into a ski jump bucket energy dissipator. For safely passing 1 in 1000-year flood of 86,900 m^3/s with maximum reservoir water level EL 140.21 m, 30 gate spillway was provided; service spillway having 23 blocks and auxiliary spillway having 7 blocks, all of 23 m width.

The perspective view and cross-section of the dam are given in Figures below.

Figure: Perspective view of Sardar Sarovar Dam s

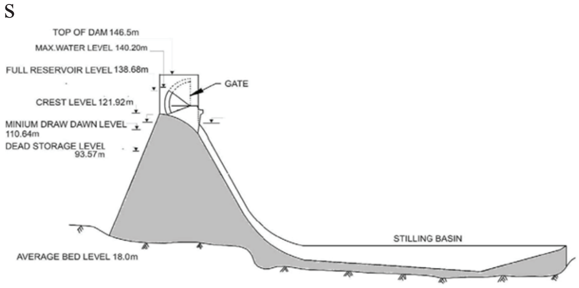


Figure: Cross-sectional view of the Sardar Sarovar Dam

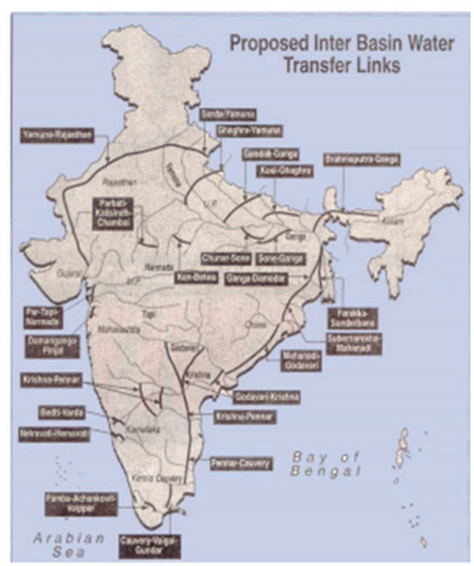
The dam's main power plant houses six 200 MW Francis pump-turbines to generate electricity and include a pumped-storage capability. Additionally, a power plant on the intake for the main canal contains five 50 MW Kaplan turbine-generators. The total installed capacity of the power facilities is 1,450 MW. The powerhouse complex comprises approach channel, intake dam blocks for penstocks, pressure shafts, powerhouse caverns to house 6 units of 200 MW reversible turbine generator and other ancillary openings for access tunnel, control room, bus shaft, ventilation shaft, etc. and tailrace system comprising 6 draft tube tunnels, collection pool, 3 tailrace tunnels and tailrace channel and switchyard. In addition, 5 X 50 MW canal Powerhouse.

Way Forward: Looking into the prospects of assuring water security with measure for augmenting water storage and diversions and Country's Interlinking of Rivers Programme under consideration

A critical look at the current situation prevailing in the country reflects that India continues to face both floods and associated disasters year after year particularly with the global climate change and associated aggravated weather patterns. Securing water for its vast population that is still growing is yet an issue to be fully addressed.

The large scale diversion of water by Interlinking of Rivers as it is popularly known for the last two decades is one of the ambitious development programme that India is looking at critically in this regard. The concept has its roots to mid-eighties when Dr. K. L. Rao's dream as an engineer turned Minister in Centre, mooted the idea of Ganga Cauvery link. Well, it drove home that India should look at examining basin wise resources and demand across the country and scoping opportunities that are feasible to conserve the excess monsoon flows wherever available for transfer to areas which face shortages and drought prone. The North south and East West diversion of water amongst various river basins in the country had been engaging attention since 1980s. By now, this has been well studied. The initial plans by the National Water Development Agency, which was created by Centre to explore Inter Basin Water Transfer (known, as Interlinking of Rivers Programme since 2000, comprise of about 30 major links for diversion of water from water rich basins to water deficit basins. The scheme involves large dams and storage behind and long-distance water transfer with sizeable canals and associated structure including pumping all over the country.

PROPOSED INTER BASIN WATER TRANSFER LINKS



Long distance inter-basin transfer of water is indeed practiced all over the globe and in India, it brought in a few impressive schemes in the 20th century. The Periyar Project, the Parambikulam Aliyar Project, the Kurnool-Cudappah canal and the Telegu Ganga projects are good examples of inter-basin water transfers in peninsular India.

In the north of the country excellent examples were seen in Indira Gandhi Pariyojana, the Beas-Sutluj link. However, some apprehensions about the environmental and social impacts of the link projects had been seen on water transfer projects in India and elsewhere in the globe. Starting with a Task Force that was constituted by Government of India in 2002, the Centre had been reviewing the Project critically for several decades by now. A High Level Special Committee headed by Union Minister of Jal Shakthi is aiming to achieve a consensus with States who also participate in the Committee, and the progress is of course less than anticipated, as of now due certain requirements of States that are yet to be amicably resolved.

The benefits of the Water Transfer schemes as initiated by National Water Development Agency in 2003 are substantial and could yield several advantages to the country in its development agenda, like:

Irrigation 35 MHa; (drought prone areas are also benefited, where feasible)	Removal of regional imbalance in water availability
Hydro-power- 34,000 MW Installed Capacity	Minimum flows in rivers to enhance ecology & environment, cater to existing uses
Drinking water-supply to over 100 districts	Improved water quality
Mitigation of Floods & Damages (partial)	Increased forest cover
River flow restoration and Environmental Quality Enhancement, Reservoir and Riverine Fisheries	Inland Navigation Facilities

This impressive water project could, in the future as and when a decision is taken for its implementation offer vast challenges for Engineers of coming decades. During its implementation, large-scale employment will be created and there would be a big fillip to the cement, steel and engineering equipment industries. It is likely that the Scheme would require about 32 new dams, nearly 4,291 canal structures, 9629 km of link canals, 12, 468 km of distribution network, to quote a few engineering features of relevance. Substantial demand for Cement, Steel and other products are likely to arise during the construction phase of activities. Employment generation opportunities appear to be quite substantial and could be over 6 million man years, encompassing almost all spheres like engineering, banking and financing, etc and the skill building and education sector would receive an impetus, in order to work towards to the avowed 'Make in India' goal of the Government. The successful implementation of the programme is therefore of utmost importance for the development of the country and it is necessary that a supportive climate for the programme is created. Certainly, the environmental concerns should be looked into very carefully with the provision for mitigating measures and proper rehabilitation steps taken for those likely to be adversely affected.

The Institution of Engineers (India) participated in a review of the scheme when it was examined critically by a Parliamentary Committee of Government of India and had the pride of giving its sagacious advice by taking a position associating multi-disciplinary expertise.

Transition to future from the Past – Position of Water in a country's Agenda to meet Global Challenges

In the recent past, as is well known for those who link Indian Agenda with that of Global interests, there have been universal convergence in agreeing to 17 sustainable development goals (SDGs) in the United Nations that could transform our world for better, and these are:

1: No Poverty, 2: Zero Hunger, 3: Good Health and Well-being, 4. Quality Education, 5: Gender Equality, 6: Clean Water and Sanitation, 7: Affordable and Clean Energy, 8: Decent Work and Economic Growth 9: Industry, Innovation and Infrastructure, 10: Reduced Inequality, 11: Sustainable Cities and Communities, 12:

Responsible Consumption and Production, 13: Climate Action, 14: Life Below Water, 15: Life on Land, 16: Peace and Justice Strong Institutions, 17: Partnerships to achieve the Goal.

As one could notice, water is strongly linked to many of these laudable goals and in particular, essential in respect of achieving the targets. In tune with this objective, the steps taken by our country is worth a consideration in this paper. India had other ambitious goals through accelerated development with special emphasis in funding measures so that targets as set beneath more or less in tune with UN SDGs described above are attained.

TARGETS

- By 2030, achieve universal and equitable access to safe and affordable drinking water for all.
- By 2030, achieve access to adequate and equitable sanitation and hygiene for all and end open defecation, paying special attention to the needs of women and girls and those in vulnerable situations.
- By 2030, improve water quality by reducing pollution, eliminating dumping and minimising release of hazardous chemicals and materials, halving the proportion of untreated wastewater and substantially increasing recycling and safe reuse globally.
- By 2030, substantially increase water-use efficiency across all sectors and ensure sustainable withdrawals and supply of freshwater to address water scarcity and substantially reduce the number of people suffering from water scarcity.
- By 2030, implement integrated water resources management at all levels, including through transboundary co-operation as appropriate.
- By 2020, protect and restore water-related ecosystems, including mountains, forests, wetlands, rivers, aquifers and lakes.
- By 2030, expand international co-operation and capacity-building support to developing countries in water- and sanitation-related activities and programmes, including water harvesting, desalination, water efficiency, waste-water treatment, recycling and reuse technologies.
- Support and strengthen the participation of local communities in improving water and sanitation management.

In line with the objectives, there had also been a Shifting focus from Development to Management in recent National Water Policies and Water Framework approaching the issues holistically by River Basin Management approach. Some discussions on these targeted activities are as follows:

NATIONAL WATER MISSION

The Country's National Action Plan on Climate Change (2007) had evolved National Water Mission as one of the eight missions to effectively address the impact of climate change on water resources. One of the important goals identified for National Water Mission is promotion of basin level integrated water resources management. The demand on water by different sectors for sustaining the pace of development, food security, changing life style and environmental concerns is ever increasing. It is clearly emerging from all recent policy documents of the Government at Centre that there is an urgent need to adopt river basins as the fundamental block for integrated planning, development and management of water resources in the country in order to tackle present issues being faced by the water sector and the future emerging challenges in the sector. Critical reviews followed by legislating appropriate Riven Basin Act are in progress in consultation with States while, pari-passu several recent programmes were launched in a unique way to accelerate the progress.

WATER CONSERVATION

These water conservation efforts throughout the India is also being given particular focus so as to ensure that not only major, but also mini and micro level measures also receive due attention with the support of the Governments at Centre and States. While big is bountiful, small is beautiful. Widespread water conservation measures help multi-faceted action at grass root levels and were requiring special interventions from State. Hence, development of block and district water conservation plans, stood up in recent priorities in water sector and the engineering professionals were gearing themselves to promotion of efficient water use for irrigation in association with groundwater experts and scientists. India's most water-stressed districts are given importance in areas like water conservation and water resource management by focusing on the accelerated implementation of the following five target interventions. i) water conservation and rainwater harvesting, ii) renovation of traditional and other water bodies / tanks, iii) reuse and recharge of bore well structures, iv) watershed development, and v) intensive afforestation. These water conservation efforts were also supplemented with special interventions district water conservation plans, and the promotion of efficient water use for irrigation.

SWATCH BHARAT MISSION

Swachh Bharat Mission, the world's largest sanitation and behavioural change program that gets accelerated in the recent times all over the country soon after declaring India to have a Swatch Bharat and ensure the Nation is open defecation free (ODF). The SBM-is unique as no other sanitation program anywhere in the world has ever managed to achieve the targets. India went from having sanitation coverage of under 40% in 2014 to achieving universal sanitation coverage in just five years. Over 10.5 Crore toilets were constructed and more than 60 Crore people have changed their behaviour of open defecation. More than 6 lakh villages declared themselves ODF; naturally, this resulted in the Indian Prime Minister getting the prestigious Global Goalkeepers for India's prioritization in Sanitation front and thus contributing to the global progress towards Sustainable Development Goal 6 through the Swachh Bharat Mission. India contributed to reducing the global open defecation burden by over 50%, as per statistics, an impressive record, globally.

'Namami Gange' (River Development in general and more so on the Sacred Ganges River, to begin with)

Ganga has been part of collective consciousness of India and is considered the most revered river in India. Apart from a significant faith in Ganga that Indians have at large, this river is also the source of their sustenance, critically important for economy, food security and livelihood. It is difficult to imagine India without Ganga. Public participation is largely responsible for the unprecedented improvement in the water of river Ganga in the last 5-6 years. Under a specific Centrally supported initiative called Namami Gange, significant action to launch 313 projects are actively in progress and many of these are oriented to ensure water quality standards are being met with while water after abstraction, gets back to the river duly treated following current level high standards by engineering measures. As well known, the sense of faith and responsibility of the people towards Maa Ganga is admirable. On the occasion of Kumbh 2019, satisfaction over the cleanliness of the river Ganga was visible when devotees thronged in millions to take a dip in the river. This sense of appreciation in the country and abroad stems from the contribution of the public in keeping the river clean apart from specific measures taken in ensuring Sewage Treatment Plants in all the cities adjoining the river besides zero pollutant discharge into the river by Industry that follows rigorous water positive measures, thanks to recent positive developments in recent times applied engineering and large scale STP and ETPs with international collaboration.

SANITATION

The overall proportion of Indian households with access to improved water sources increased from 68% in 1992-93 to 89.9% in 2015-16. However, in 2015-16, 63.3% of rural households and 19.7% of urban households were not using improved sanitation facilities. According to the World Bank, more than 520 million in India were defecating in the open – the highest number in the world. This figure is expected to have reduced significantly given that improving sanitation is a key priority of the government which has introduced several flagship programmes including the Swachh Bharat Abhiyan to clean India, the National Rural Drinking Water Programme, and 'Namami Gange', which aims at the conservation of the River Ganga.

SDG Report 2020 on Vision for SDG 2030 No.6 Water & Sanitation

The coronavirus crisis has brought to the fore the critical importance of water, sanitation and hygiene for protecting human health. Despite progress, billions of people across the globe still lack these basic services. Immediate action to improve access to water, sanitation and hygiene services is required to prevent infection and contain the spread of COVID-19. Water is essential not only to health, but also t o poverty reduction, food security, peace and human rights, ecosystems and education. Nevertheless, countries face growing challenges linked to water scarcity, water pollution, degraded water-related ecosystems and cooperation over transboundary water basins. In addition, funding gaps and weak government systems hold many countries back from making needed advancements. There is recognition that unless and until the current rates of progress increase substantially, Goal 6 targets will not be met by 2030.

CONCLUSIONS

The challenge before the engineering profession has thus been manifold in days ahead which ask for both water resources and development action of varied prongs. Integrated Water Resources Management to achieve them call for local actions for a global challenge and efforts to handle them within the framework of available constitutional provisions is not that easy unless and until professional institutions like The Institution of Engineers (India) join hands with others in its National Efforts.

Most of the future steps in a steady manner require multi-disciplinary coordinated efforts in Water Sector (including Power) and will be spread out in research, development and profound action in field. Not only public sector but also private sector participation involving public participation alone can yield fruitful results. Happily many action plans like Swatch Bharat, Har Kheth ka Pani etc recognise the dire necessity of an inclusive and cooperative, concerted action. India shall rise up to the occasion and work with not only Governments and other players including academia but also other professional bodies in various disciplines that play active roles in the development Agenda.

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Author's Profile

Prof C Balaji is currently the T T Narendran Chair Professor in the Department of Mechanical Engineering at the Indian Institute of Technology (IIT) Madras, India. He graduated in Mechanical Engineering from Guindy Engineering College, Chennai, in 1990 and obtained his M.Tech (1992) and Ph.D. (1995) from IIT Madras in the area of heat transfer. His areas of interest include heat transfer, computational radiation, optimization, inverse problems, satellite meteorology, and atmospheric sciences. He has more than 200 international journal publications to his credit and has guided 30 students so far. Prof Balaji has several awards to his credit and notable among them include the Young Faculty Recognition Award of IIT Madras (2007) for excellence in teaching and research, K N Seetharamu Award and Medal for excellence in Heat Transfer Research (2008), Swarnajayanthi Fellowship Award of the Government of India (2008-2013), Tamil Nadu Scientist Award (2010) of the Government of Tamilnadu, Marti Gurunath Award for excellence in teaching (2013) and Mid-Career Research Award (2015) both awarded by IIT Madras. He is a Humboldt Fellow and an elected Fellow of the Indian National Academy of Engineering. Prof.Balaji has authored 8 books thus far. He is currently the Editor-in-Chief of the International Journal of Thermal Sciences.

Industry-Academia Interaction

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INTRODUCTION

Industry and academia are two indispensable pillars in the progress of any civilization or society, country and by induction, the world [1]. If one looks at the great strides that have taken place in the last few centuries in the fields of science, technology, engineering and medicine (STEM), one can see that often great ideas have originated from academia and research laboratories. All round progress critically hinges on a strong interaction between industry and academia that exerts a synergistic influence in many ways such as the (i) exchange of ideas between industry and academia, (ii) smooth transition of research from academia to the industry, (iii) building an industry-ready workforce leading to more innovation. The two-way exchange of ideas helps the industry march forward and at the same time helps academia focus and work on more challenging and topical problems that often turn out to be translational. In view of the above, endeavours to increase industry-academia interaction are essentially work in progress all over the world and will continue intensively in the years to come.

At first sight, industry and academia appear to have different mindsets as they pursue seemingly different and orthogonal goals. The goal of an academic is generally to gain recognition from peers by producing high-quality research articles, innovate and come out with new inventions and ideas, and of course above all graduate good and capable students who directly become a part of the workforce or think tanks in a nation. The goal of the industry, on the other hand, is to make products or services that are directly useful to the customer. A key requirement here is that the endeavour should make commercial sense as there is an investment of time, money and effort in starting and running an enterprise. The goals in academia are long-term (Universities have existed for a few hundred years now!) from a scientific or engineering perspective as technologies, products and services are constantly evolving with the new replacing the old, whereas the goals of the industry are typically short-term to medium-term. Academia is focused on creating a new and exciting solution which may or may not be commercially viable, whereas industry prefers solutions that are tried and tested and workable or a new solution that is highly risky if there are very high rewards. Even so, huge investments are involved, and the stakes are often very high and many enterprises may not be willing to invest millions in an unproven technology [2]. Notwithstanding this to have a vibrant innovation ecosystem, start ups will look for funding from angel investors and venture capitalists.

NEED FOR INTERACTION

Industries require state-of-the-art solutions from academia or from any other source that relied upon for that matter to keep up with the growing needs of the business by increasing productivity and reducing costs, thereby increasing the profit to stay in the race and edge past the competitors. A foreign collaboration is often a preferred route as the product and or service is already proven elsewhere. Notwithstanding this, burning issues involving intellectual property and so on coupled with the fact that such a collaboration may itself become a stumbling block for in house research and development are downsides to this. Government policies and international agreements that keep changing from time to time can also be unpredictable.

Hence, for more reasons than one, a synergistic collaboration between academia and industry can be a big boost. Most industrialized nations do follow this model.

Additionally, since obsolescence is high in almost every sector, new ideas, solutions, products, and services have become an absolute necessity to stay in business. Many of the start-up ecosystems across the world, such as Silicon Valley, Beijing, Seoul, London, or Tel Aviv, had universities giving the initial impetus for the innovation [3]. The applied research that was going on at these universities in different areas of research has often played a critical role in the development of the start-up ecosystem.

Interaction of academicians with industry is first required for the academics to understand the latest technologies that are implemented in the industry. Having done this, they will be in a position to come out not only with improvements but also look at better ways of doing a particular thing or better still a new way of executing a particular project or developing a product or solution based on their domain competence and their inherent ability to go very deep in one particular field. At an institute or university level, working on the sponsored research projects and consultancy assignments from the industry helps academicians with funding that can help them sustain their broader research interests, support research students and build setups, test rigs, or scale-up computational resources. A meaningful, intensive interaction of industry and academia leads to job creation and overall progress, and also helps academic research become more translational and industries more aware of the competencies in trouble shooting, problem solving and ideation in academia.

GUIDING PRINCIPLES FOR INDUSTRY-ACADEMIA INTERACTION

The following principles may be used as broad guidelines in fostering the industry-academia interaction:

a. Open academic environment: The administration, the academic senate, and departmental faculty need to take the responsibility to establish appropriate rules and regulations for the existence of an open and free environment.

b. Freedom to publish: An important condition for the research project is the freedom to publish, which is fundamental to the university. Many products that have come today are based on principles that were published in the past or have been patented. Faculty need to be encouraged and nudged to engage in projects outside the university. These activities, in general, should not largely interfere with the primary duties of the faculty, such as teaching and research duties, but rather complement the above.

c. Creation of Professors of practice (POP) position: Universities and higher institutes of learning may be encouraged to set up Professors of practice (POP) positions in major departments and invite distinguished leaders from industry to take up these positions in the academia for a period varying from 1-3 years with flexible work engagement rules, and the actual time to be spent in a week or month or a term. An important objective of setting up POPs would be the establishment of centres of Excellence (COE) in very specific areas in line with the Government's plan, and push for "Make in India".

d. Encouraging faculty sabbaticals to industry: Faculty may be encouraged to spend a sabbatical ranging from 2-6 months in an industry that is closest to their research interests and competencies, to explore the possibility of working on a problem exciting

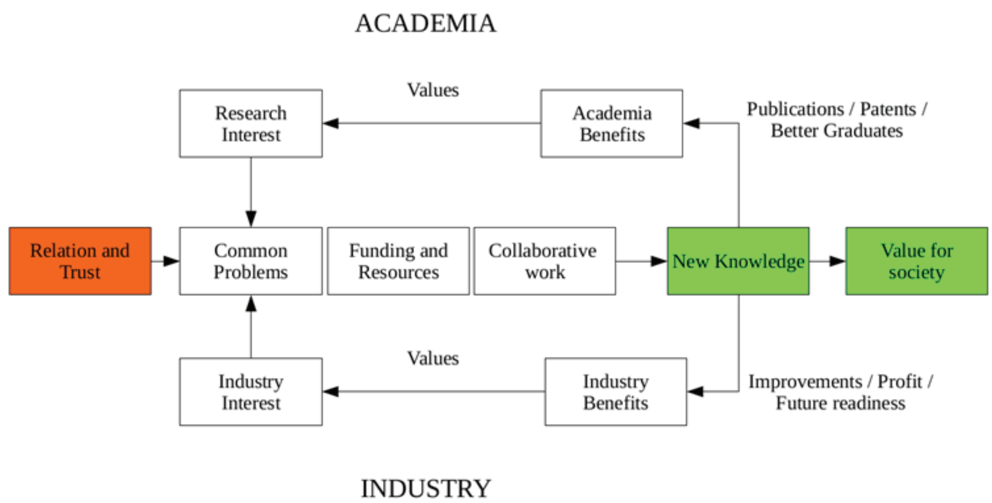

Fig. 1 : A bird's eye view of the mechanics of Industry-academia interaction

to both the academia and the industry. Such industry stints may pave the way for long term fruitful and productive industry-academia collaboration.

NATIONAL EDUCATION POLICY 2020

The National Education Policy (NEP) 2020 [4] has also discussed at length about improving the collaboration of industry and academia. The policy recommends the establishment of the National Research Foundation (NRF) that will seed, grow, and facilitate research at academic institutions; create beneficial linkages between researchers, government and industry and recognize outstanding research. According to the NEP, interactions leading to innovation and research need to be strengthened considerably between industry and institutions offering technical education.

"To encourage such interactions, accreditation/ ranking will incentivize:

1. Industry-academic collaborations such as establishing industry centres of excellence and incubation cells in institutions (with joint funding and protections for intellectual property).
2. Appointing faculty with research and industry experience, in addition to academic qualifications; the latter by themselves will not be considered adequate qualifications for technical faculty.
3. Offering positions to selected industry experts on boards of studies and as adjunct faculty.
4. Creating internship opportunities for learners, especially with nearby industries, to develop products to address local needs. Industries will report such collaborative activities in their annual reports, under CSR expenditure.
5. Using state-of-the-art resources for educational purposes, particularly by sharing expensive equipment with industries or by using virtual laboratories to access resources located elsewhere.
6. Public and private sector enterprises and organizations, including philanthropic organizations, will also be given the opportunity to participate in the NRF's research mechanisms similarly. Providing funds for specific research needs through the NRF will have the advantage of helping enterprises and organizations identify academic groups in the country with the expertise they are looking for. They will also benefit from the peer-review process of the NRF for allocation of projects to specific research groups, and be able to ensure that their research projects receive adequate oversight. The process of

funding research through the NRF will also help develop links between academia and the concerned public and private sector companies and organizations. Subject Committees of the NRF may each contain one representative from the respective organizations during deliberations of funding from these sources.

7. Donations from industry: It is suggested that all public and private sector enterprises will contribute a small percentage, say at least 0.1%, of their annual profits to research (such as donations for research to the NRF). This could be done within or outside CSR funds and such contributions would come with suitable tax incentives."

The above clearly shows the national priorities in intensifying and incentivizing industry-academia collaboration. The NEP has articulated the broad contours of the interaction at the research level fairly comprehensively.

RECOMMENDATIONS AND POSSIBLE STEPS FORWARD

Based on whatever has been presented in the earlier parts of this paper and taking a cue from NEP 2020, the possible steps forward are listed below,

1. Centres such as the Centre for Industrial Consultancy and Sponsored Research at the Indian Institute of Technology Madras help in the promotion, facilitation, coordination, and administration of all the sponsored and consultancy projects handled by the faculty. Setting up this kind of centres at the universities can help kick starting and improving industry-academia interaction. Innovation and patenting need to be encouraged at the institute level. Once patents are filed, there could be a mechanism in these centres by which industry representatives can get connected with inventors so that the concept is taken to its logical end and comes out as a product that is technically sound and appropriately priced. Efforts to scale-up need to be made.
2. Academia needs to reorient its work to ensure that it meets the expectations of the industry without hampering the regular activities like teaching, student guidance and research. Starting with a small budget and short-term projects from industry and successfully executing those gives confidence both to the researchers and industry. A transition to bigger projects can then be made, and these should eventually lead to creation of large centres of excellence with participation from the industry and other institutes.
3. Academic institutions need to, not only focus on the areas with basic research, but also in areas involving translational research with societal impact, which at the same time be useful for industry and make it more competition ready. Nation specific research is not only important, but is essential in attracting industry to academia with projects and funding.
4. An increase in the participation of people from the industry in academic conferences, symposia, workshops and vice-versa needs to be encouraged, as these invariably lead to an interesting and crucial exchange of ideas.
5. Faculty at the universities may be encouraged to take up more sponsored projects from the industry and also provide consultancy services to small scale industries that have limited equipment and resources while at the same time keep their engagement with medium and large scale industries.
6. Faculty members may be allowed to spend a sabbatical at the industry related to their field of expertise to understand the requirements of the industry and improve relations as well as trust. These interactions help assess the core competency areas of the faculty as well as the industry, leading to a more fruitful collaboration.
7. Industries may be encouraged to set up centres of excellence at academic institutes. Centres of excellence can, apart from carrying out cutting edge research of mutual interest, act as

the bridge between the industry and academia by organizing various events such as series of lectures and presentations from the industry, competitions with industry-specific problem statements, group discussions, and industry visits. These centres help students get a first-hand experience of how an industry functions.

8. Professors of practice (POP), i.e. 1 or 2-year teaching engagement at the university for people who are highly accomplished in the industry. Provision of having honorary professors/faculty both from the industry and research and development organizations gives an exposure to the students of interacting with working professionals. Several laboratories have already been sponsored by the industry, and software worth millions of rupees have already been donated by technology companies. These may be further strengthened.

9. Establishment of the university-based research parks. Venues may be created for close interaction, starting from conceptualization down to commercialization. These research parks act as hubs for the technology start-up incubation centres. The critical reason for the research not being able to reach the market is often the capital and operational costs. Such research parks may help provide resources for setting up and scaling the operations. Interactions with the industry and tie-ups can help in the faster and fruitful transition of the research to the working product.

10. Universities need to be encouraged to develop specific programs to enable up-skilling of people from the industry. Web-enabled specialized/tailor-made program or user-oriented programs. For, e.g. at IIT Madras, there is an automotive technology program at the Master's level that is web-enabled and is open only to working professionals sponsored by their companies. Many such programs do exist in other IITs and institutes of national importance. External and part-time registration in the universities for the sponsored candidates from the industry to pursue their Masters and/or Ph.D. may be strengthened so that such individuals become brand ambassadors for the collaboration and cooperation.

11. Having representatives from the industry in the Board of Governors or Governing council of institutes can help the universities to design the curriculum better so that the students will be industry-ready by the time they graduate [5]. Every major department is expected to have a research advisory committee with representatives from the industry. This helps in not only designing the curriculum to meet the challenging needs of the industry but also helps the industry connect through visits, guest lectures and summer internships.

12. An increase in the student internships in the industry can help the student gain exposure to how things work in the industry and learn from the experience. As the students have a lesser cognitive bias, they look at some of the problems from a different angle, which can help improve some of the processes in the industry. The internships are also potent in improving placement outcomes through pre placement offers, off campus offers and so on.

13. Apart from industry, an increase in collaboration with Government laboratories such as the Council of Scientific and Industrial Research, Defence Research and Development Organisation, Indian Institute of Tropical Meteorology, Structural Engineering Research Centre, National Chemical Laboratory, and successful research organizations like the Indian Space Research Organization (ISRO), to name a few, help the faculty from the universities get an idea of the current research problems that the Government laboratories are working on and by way of this, collaboration could be made synergistically.

14. An important issue to look at is regarding the patent rights from the research projects. When the industry is involved in a research project,

the academic institutions are sceptical of losing the patent rights to particular research. Nevertheless, several academic researchers gain from their research through the writing of books, industry consulting and speaking engagements. This shows that academic research and the pursuit of profit may not always be mutually exclusive.

CONCLUDING REMARKS

As we complete 20 years in the 21st century, we are at the crossroads. Progress in the world and in the country depends not only on the availability of land, capital, labour, and favourable individual climate but is critically dependent on rich human resources, innovation, and creativity and the willingness to come out of one's comfort zones. These are equally applicable for both academia and industry. In this brief paper, we saw that these two are nothing but two sides of the same coin. With this recognition, together with the fact an that intensive, meaningful and mutually respectful industry-academia collaboration is a win-win for both, this interaction has to be pursued vigorously and more aggressively, as the nation has given a clarion call for a very ambitious "Make in India" initiative.

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Engineering for Inclusion - Affordable Innovations in Assistive Devices

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INTRODUCTION

As human beings, we all have abilities and limitations. Technologies that help enhance our capabilities or compensate for our limitations can all be termed assistive technologies. For instance, most of us need eyeglasses to enable our eyes to function well. Machines such as levers and screws are engineering marvels that provide the ability to do more with our limited human capacities. And yet, we see assistive technologies as devices required only by people with disability, leading to a stigma associated with their use.

The World Health Organisation's (WHO) report on disability shows that more than 1 billion people (almost 15% of the world's population) live with some form of disability and in general, the prevalence of disability is growing around the world [WHO 2011]. In India, the 2016 census reports that there are over 27 million people with disability (PwD) [Census 2016], and most of them lack access to the appropriate devices needed for them to be productive members of society. In many cases, the incidence of impairment leads to loss of an existing job, lack of new accessible opportunities and economic dependence, which can have devastating consequences to the quality of life of PwD.

While there are various aspects – functional, social and psychological – to the inclusion of people with disability, the first requirement is the availability of appropriate assistive devices for rehabilitation after the injury that caused the disability, as well as to restore function. The focus on function is important to enable the person to be as independent as possible with respect to mobility and conducting their activities of daily living (ADL). Engineering for inclusion should take into account ADL, mobility, education, employability and social participation. The UN convention of the rights of people with disabilities states that PwD have a right to affordable and accessible assistive technology [Borg et al. 2011].

Some of the countries such as, USA, Japan, Australia, Canada and Europe are able to provide assistive technologies (ATs) to their citizens who need them. In most of the cases, this is made possible through Government led programs, distribution schemes and providing subsidy. The penetration of ATs in India is not significant for various reasons. Firstly, the number of people who need assistive technologies is large. India has a population of 2.68 Crore when it comes to people with disabilities, of which the majority of them live in rural areas. The awareness among people about ATs and their potential to empower is not known. There are no strong marketing and dissemination channels to reach people who need them. Further, India has a huge shortage of Assistive Technology experts, trainers and technicians.

ATs are largely not market driven technologies. There are not many manufacturers of assistive technologies in India. The ATs developed and marketed by western countries are largely not affordable to the Indian population. Moreover, in western countries ATs are developed keeping in mind the structured environments which exist in those countries. The same ATs do not perform well when they are used in countries such as India. These unmet needs point to scope for engineering assistive technologies in India that are safe, affordable and usable. The efforts and investment in Assistive Technologies not only empower people with disabilities, but will bring economic prosperity when people with disabilities contribute to nation building like any other person. These efforts will also bring social advancement in many ways as addressing disability helps in addressing 6 of the 17 Sustainable Development Goals [UN Resolution 2015].

STATE OF ASSISTIVE DEVICES IN INDIA

Assistive devices available in India tend to fall at two ends of a spectrum [Rohwerder 2018]– on one end are the very low-cost indigenous or imported devices, such as the ubiquitous depot wheelchairs or drop-lock style knee joints for orthoses and prostheses. At the other end of the spectrum are exorbitantly expensive imported devices such as microprocessor-controlled knees for prostheses, bionic arms, sophisticated motorized wheelchairs, etc. The former are usually of the one-size-fits-all variety, of poor quality that cannot last for long in Indian conditions (eg., uneven terrain) and are therefore, in many cases, rejected by the users due to poor functionality. The high-end imported devices are affordable to a very few, but even those devices may not be suitable for Indian environments, and are very difficult to maintain or repair if something goes wrong. There is a pressing need for devices designed with Indian users and conditions in mind, while keeping in mind the cost-sensitive nature of the market.

Technology can play a role of equalizer in bridging the gap between Disability and Ability. The assistive technologies which have been developed so far and new ATs needed for future activities of daily living is large. However, WHO has come up with a small set of 50 priority assistive devices. Most of these are beyond the reach of Indian people with disabilities. This points to urgent action needed and responsibilities of engineers to develop the same. Being an interdisciplinary activity, empowerment through assistive technology calls for engineers in India need to work closely with many stakeholders as a team which includes Innovators, Entrepreneurs, Inclusive Designers, Manufacturers, Special Educators, Policy Experts, Healthcare Professionals, Government, etc. The challenges outlined underscore the need for designing AT that is specific to the Indian setting, in terms of cost and functionality.

The market is cost-sensitive due to various reasons:

Low Purchasing Power of the End Users

A disability usually results in loss of employment due to reasons such as inability to commute and lack of accessible work environments. The lack of economic independence leads to an inability to afford an appropriate assistive device.

Donation Driven Market

The primary access to ATs, especially for people who cannot afford them is through NGOs or Government camps. The motivation in these modes of distribution is to maximize the number of people served and hence, quality may take a back seat to cost. The impact of the donation in terms of improvement or lack thereof on the quality of life of the PwD is seldom measured.

The cost-sensitive nature of the market presents the following challenges:

1. Lack of investment from private industry for R&D

   Private industry is unwilling to invest in R&D to develop AT since the market is relatively small, it is fragmented geographically and the user needs are diverse, even within the same kind of disability. For instance, in users with Spinal Cord Injury, abilities can vary widely depending on the level of injury, which affects the market for a device further. The level of customization required in devices also makes mass manufacturing to reduce costs challenging.

2. Lack of competition to existing players

   A few big players at either end of the spectrum control the market. The well-known foreign players cater to a niche market. The low-cost players, including cheap imports cater to the donation market. Users also do not demand or complain since they do not want to appear ungrateful for the donations, resulting in widespread proliferation of cheap, sub-standard devices.

Therefore, it is hard for new players to change existing mindsets regarding cost, use traditional business models in a sustainable fashion and penetrate the market. There is a need for innovation not only in ATs that are more suitable to Indian conditions, but also in collaborative models of development that ensure quality, affordability and sustainability.

ROLE OF ENGINEERING INSTITUTIONS IN TACKLING THE CHALLENGE

Over the past decade, one can see a significant change in the role of educational institutions in India and worldwide. Apart from knowledge dissemination (teaching) and knowledge creation (research), institutes and universities are slowly adopting knowledge application (innovation) as a third pillar of their activity. They have come forward and equipped themselves through modification of their educational and research programs to address major grand challenges facing our society. A few institutions in the country have already leveraged technology and innovation in addressing some of the grand challenges. More and more institutions are likely to join this endeavour and can be potential public spaces for innovation in future.

India has a large pool of a new generation of students who have shown vast interest in working in multi-disciplinary teams towards solutions for societal/industrial needs. This interest among students is clearly evident during the last decade, which saw an exponential increase in student innovation activities and campus incubated start-ups. Institutes and universities are now trying to leverage this strength in building an ecosystem to take innovative ideas from classrooms/labs to market/people/society.

Engineering institutions and research centres can be effective nodal points for the development of affordable assistive devices. Access to high quality and enthusiastic manpower, ability to set up collaborations with other stakeholders and attract funding are some of the advantages of this approach. Challenges include the floating population of students, which results in projects languishing at early stages for long durations, since most students want to start afresh rather than working on improving an existing solution designed by predecessors.

Formalizing engagement of students through competitions like periodic Makeathons or Hackathons, similar to the FSAE competition, will ensure continuity of development as students leave and others come in. For example, Purdue University has a program called EPICS, which follows this model to tackle socially relevant projects in the community.

Addressing problems through student projects also can help provide solutions to bespoke problems, which may not have a large market or be suitable for commercialization, but could still make a big impact in the lives of one or a few PwD.

Universal Design should be a part of the engineering curriculum. Just as some of the features of smartphones such as voice typing have enabled accessibility, technologies that naturally scale in usefulness to a larger section of the population become easily accepted.

Through a mixture of coursework and projects, academic institutions can help tackle the challenge of engineering for inclusion. Sensitizing the next generation of engineers to concepts of universal design and accessibility, tackling user-centric assistive device problems through projects, encouraging entrepreneurship in AT are some of the ways academic programs can help instill a sense of social responsibility in our future professionals. Some case studies and learnings are presented here.

CASE STUDIES: ASSISTIVE DEVICES FOR MOVEMENT IMPAIRMENTS FROM IIT MADRAS

The TTK Center for Rehabilitation Research and Device Development (R2D2) in the Department of Mechanical Engineering at IIT Madras is involved in biomechanics research and the development of assistive devices for people with locomotor impairments. The mission of R2D2 is to use appropriate technology to develop indigenous, innovative and affordable assistive technology of high quality for people with locomotor disability, specifically for India and low resource settings. R2D2 engineers affordable products for rehabilitation needs by working with clinical specialists, NGOs, hospitals, etc., to understand needs and field-test the designs, partnering with like-minded industries or startups, while fostering a research environment to evaluate assistive device designs from biomechanical and functional standpoints.

Academic labs like R2D2 are uniquely positioned to meet the challenges of assistive device development. Most of the work in such settings starts off as student projects - internships, final-year projects, supported by rigorous research by MS and PhD scholars, where applicable. In many cases, the engineering problems can be solved at least to the proof-of-concept level by senior undergraduates and Masters students, since the state of AT in India is such that many simple problems need to be solved - it is simply that these problems have not been addressed before. For the students, it gives them an opportunity to address an engineering problem from the need identification stage to conceptual design to detailed design and analysis, and undergo the process of iterative design until the building of a prototype and field testing, if possible. **Fig. 1** details the steps involved in the process followed at R2D2. While patents and publications may be natural outcomes, R2D2 strives to take the designs at least to the level of a pre-commercial prototype where possible to enable easy technology transfer. Students are very motivated when they realize that their work can make a tangible difference.

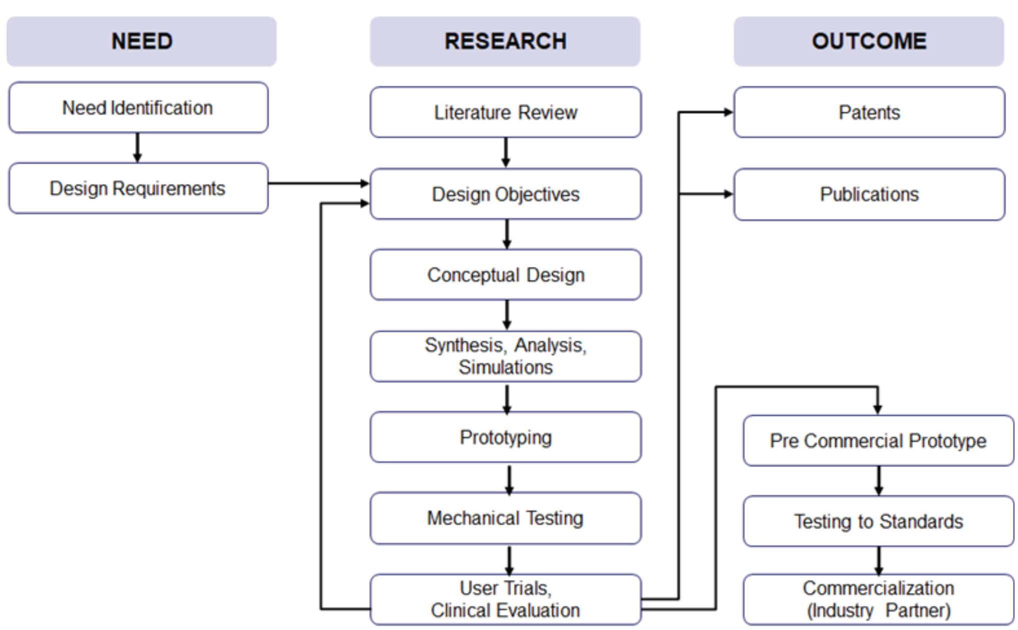


Fig. 1 : Framework for R&D of assistive devices at R2D2, IIT Madras

At R2D2, the infrastructure for mechanical testing of prototypes has been set up - prosthetic and orthotic components and wheelchairs can be tested to their ISO standards during the development using test setups. In addition, facilities for prototyping have been set up and the presence of experienced technical staff to help with fabrication helps the students realize prototypes more easily. Replicating this model in other academic institutions and creating a needs bank with problem statements and design briefs can help develop solutions to many bespoke challenges, since not every assistive device may have a large market.

For assistive devices that are needed by many users, like wheelchairs, commercialization is a must to ensure impact. Typical business models are unlikely to result in affordable devices because of the fragmented nature of the market and the high costs of R&D. There is a need for increased awareness creation and new development models that enable translation of the assistive devices to the market. One such model that has been implemented at R2D2 is what we call the GRID model. The Grants-Industry-Research-Dissemination (GRID) model is ideally executed by academic and research institutions for R&D and translation in areas that do not lend themselves to the traditional business models involving investors, a consumer market and a focus on financial returns of investment in the short run. The GRID model **(Fig. 2)** is a collaborative model with four pillars where a

Fig. 2 : The GRID model for assistive device development

research institution takes in grants from funding agencies focused on social impact, ropes in an industry partner or encourages the setting up of a startup and works with dissemination partners throughout the development process - from the establishment of user needs to the utilization of awareness creation, fitting, training infrastructure of the network of NGOs, hospitals, rehabilitation centres, etc. to reach the end users with the product. The four pillars are:

Grants: Funding agencies focused on social impact provide flexible grants specifically targeted to R&D of AT until the pilot production and commercialization stage. The cost of AT development could be borne by the government, foundations or CSR (Corporate Social Responsibility) grants from private industry. The primary focus of the grant is creating impact, not financial return. Support should include funding for the industry partner for the development of manufacturing fixtures, tooling, etc. to encourage their participation with low risk. Affordability can be ensured by ensuring that the markup on the final product is kept low - sufficient to ensure sustainability of operating costs, but without the need to recoup R&D costs.

Research: The nodal academic/research institution is the key player bringing all the pillars together. The research institution has access to the grants mentioned above, which are typically not directly accessible to private industry. Besides, it can perform the research with scientific rigour and appropriate technology with a focus on meeting user needs, instead of just the bottom line. The extensive access to additional human resources in the form of students, testing infrastructure and expertise available for the research act as grant-multipliers for the development.

Industry: The Industry partner could be one with established manufacturing capability and expertise, not necessarily in assistive device manufacturing, but perhaps in allied fields. They should have the ability to manufacture a new product line at low costs. They are also likely to have established channels for marketing, sales and service that could be leveraged for the new AT products. The industry partner could also be an innovative and agile startup with a singular focus and urge to succeed.

Dissemination: The dissemination partner(s) provide the connect to the end users throughout the design process. Their involvement is critical to ensure that the user needs are understood well, periodic feedback is obtained on the design from potential end users, and once the product is available, proper fitting and training infrastructure is established to ensure an optimal user experience with the product. NGOs involved in disability, user groups of PwD, rehabilitation centres and hospitals are likely dissemination partners since in most cases, they are the ones creating the awareness about available products.

A sampling of various R2D2 projects at the undergraduate, postgraduate and doctoral level that are geared towards assistive and rehabilitation devices are detailed below:

Arise Standing Wheelchair (SWC)

For wheelchair users, standing is a necessary activity to prevent secondary problems like pressure sores. However, it is very difficult to accomplish without assistance. R2D2's SWC design enables the user to self-stand in the wheelchair and requires low muscular effort because of the optimized spring-balancing. The design can be customized to various users and has been commercialized as the Arise Standing Wheelchair **(Fig 3)** at an affordable price of INR 15000. The development towards commercialization was funded by the Wellcome Trust, UK. The industry partner manufacturing and marketing the device is Phoenix Medical Systems, a medical devices manufacturer in Chennai.

The project started as a class project in the second-year course, Kinematics and Dynamics of Machinery back in 2011. The proof-of-concept was demonstrated by a Dual Degree (B. Tech and M. Tech) student who worked on the design as his final year project. Between 2012 and 2015, various students worked on making improvements to the design as part of summer internships. A student's final year B. Tech project in 2013 provided the theoretical work on spring balancing, which has since been applied to multiple designs at R2D2 including the Standing Wheelchair. Extensive progress was possible only from 2015 upon receiving the Wellcome Trust grant and the industry and user group partnerships, due to dedicated staff, resources and field visits available for multiple design iterations. The product was mechanically tested to ISO standards by developing the appropriate test rigs at IIT Madras. After the completion of a safety study at St. John's Hospital, Bangalore, the product was launched in November 2019.

Fig. 3 : Arise standing wheelchair, launched November 2019

Fig. 4 shows the design journey of Arise from a concept on paper as part of a class project to the finished product. It also illustrates the partners in the GRID model for development: Grant: Wellcome Trust, Research: R2D2 at IIT Madras, Industry: Phoenix Medical Systems, Chennai and Dissemination: Rehabilitation and User Community, Association of People with Disability and the Spinal Foundation.

Swimming Pool Lift: Hydrotherapy is very beneficial for people with musculoskeletal impairments since the buoyant force enables them

Fig. 4 : Timeline and design journey of the arise standing wheelchair from an undergraduate course project to product, and use of the GRID model in its development

to get much-needed exercise. However, getting into and out of the pool is awkward and arduous: they have to be pushed in and pulled out of the water, which is challenging and risky for the helpers as well. The pool lift lowers the users into the water and brings them up safely when they are done swimming. The first prototype was designed and built as part of a final year student project in 2013 **(Fig 5)**. A manually operated prototype resulted from a B.Tech project since then, but issues remain with the design and extensive user testing is necessary. Subsequent progress has been slow due to lack of student interest in improving an existing project, and lack of dedicated funds and a team for a device that may have a very limited market.

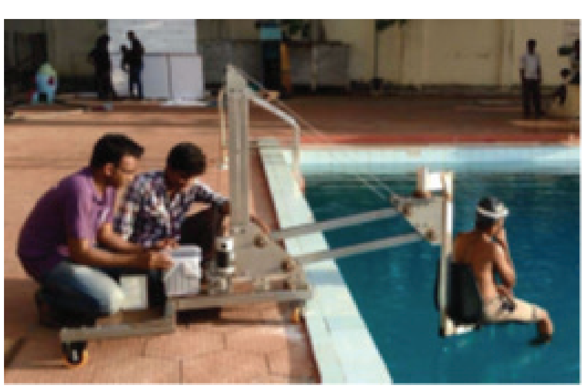


Fig. 5: Swimming pool lift

Prosthetic Knee for Uneven Terrain

Above-knee prosthesis users typically use a locked single-axis knee for stability while walking. However, a locked knee results in an unnatural gait and excessive loads on other joints. A new polycentric knee has been designed that performs better (by providing increased stability and toe-clearance) than existing imported knees. After undergoing user trials, the technology has been transferred to Mobility India, Bangalore for commercialization. The project was primarily funded for the design and trials by the Society for BioMedical Technology (SBMT).

The kinematic design and optimization of the knee geometry were the results of an M.Tech project in 2014. The student stayed back to continue work on it for another year with funding from SBMT, which enabled design, analysis, some mechanical testing and fabrication of prototypes for preliminary user trials. After a gap of two years, SBMT provided funding for user trials in partnership with Mobility India **(Fig 6)**. About 20 users were fitted with the knee in 2018 at various locations by Mobility India enabling the knee design to undergo extensive testing, especially in the kind of uneven terrain it was designed for. A PhD student has done extensive simulation work

Fig. 6 : User trial with Prosthetic Knee

related to the biomechanics of the knee functioning showing that a near-normal gait was possible with the knee. The simulations also helped to simplify the design since they showed that an extension assist is not necessary for this knee, while it is absolutely essential for the functioning of a single-axis knee. Most polycentric knees on the market (typically imported) also have extension assists. The PhD research showed that the polycentric knee design could be simplified by removing the extension assist, which had actually been a source of problems during the user trials, thereby reducing weight, cost and maintenance requirements. The PhD work also provided important insights into the alignment of prosthetic knees, further improving the design.

The technology was successfully transferred to Mobility India, a leading NGO in the field of providing prosthetics and orthotics with a presence in Karnataka, the North-east and globally in countries like Bangladesh. Since MI is not an industry, R2D2 is continuing to support them in design for manufacturing, identifying vendors, etc.

ROBOTS FOR HAND AND ARM NEUROREHABILITATION

Stroke is on the rise in India and the lack of trained therapists to administer therapy as well as the logistics of accessing therapy at rehabilitation centres and hospitals can hurt the ability of stroke survivors to regain their functionality. Rehabilitation robots that are simple to use, portable and engage the user with games can provide customized, intensive therapy to improve rehabilitation outcomes. Typically, these robots are bulky, complex and very expensive devices. In collaboration with the Department of Bioengineering at CMC Vellore, through joint guidance of Masters and PhD students, we are developing modular mechanisms for training different hand functions, and a robot for arm rehabilitation **(Fig. 7)**. A usability study of the hand rehabilitation robot has been completed with therapists and patients at the Physical Medicine and Rehabilitation Department at CMC Vellore.

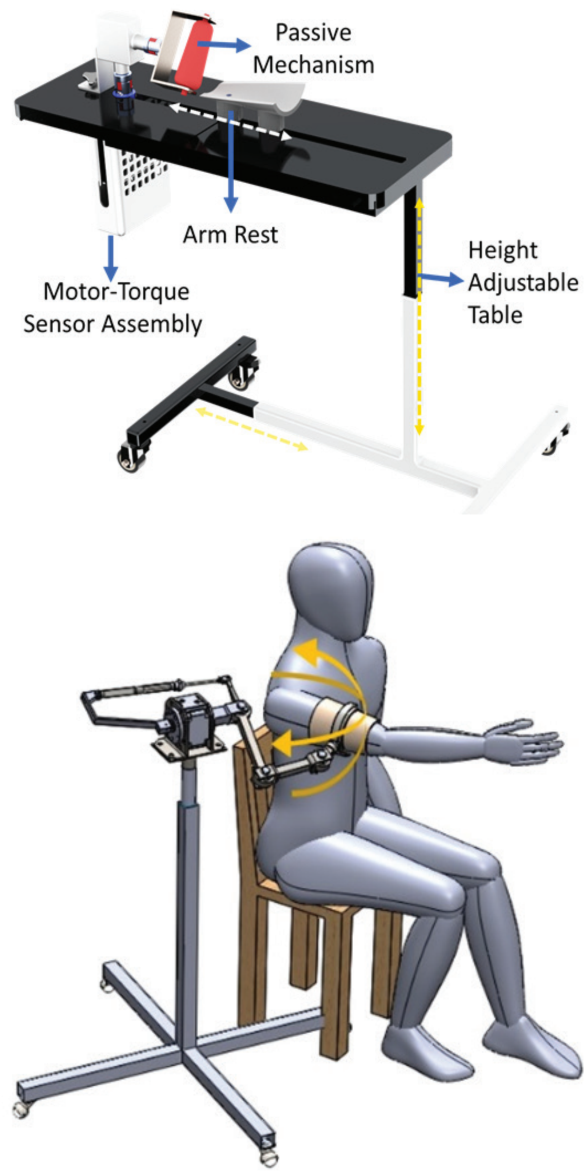


Fig. 7 : Device for (a) Hand neurorehabilitation and (b) Arm neurorehabilitation

FRAMEWORK FOR NUMERICAL DESIGN OF CUSTOMIZED PROSTHETIC FEET

The prosthetic foot is a critical component to enable a person who has undergone a lower limb amputation to walk. It is a complex system with multiple design elements such as a rigid keel encased in a complex foam system to resemble a natural foot. The geometry and the non-linearity of the materials used and contact interfaces

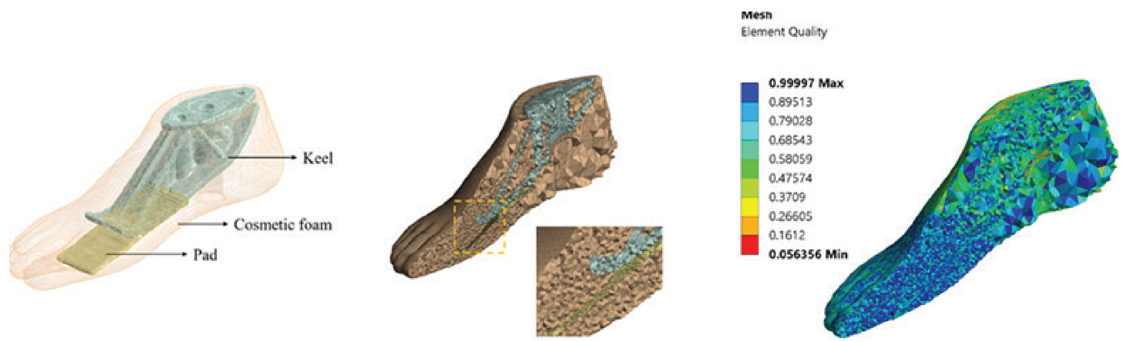


Fig. 8 : Geometry of a solid Ankle cushioned heel (SACH) foot from 3D scanning and processing and its corresponding meshed finite element model

make the analysis of a prosthetic foot complex, and because of this complexity, there have been no reliable numerical methods to understand the biomechanical behaviour. Thus, the development of prosthetic feet has been largely dependent on trial and error experimentation during design, making the process time-consuming and expensive. The novel framework developed in this work tackles the challenges due to the non-linearities and large deformations to present a model that can predict quite accurately many parameters that would determine the functionality of a prosthetic foot design. Some of the biomechanical parameters include the roll-over shape, ankle range of motion and energy storage and return of the prosthetic foot, which would enable numerical evaluation of multiple designs before prototyping and experimentation on human subjects. **Fig. 8** shows the geometry of the multi-element SACH foot and the meshed model for analysis. The approach could also pave the way for the customized design of prosthetic feet for individual users.

STARTUP: NEOMOTION ASSISTIVE SOLUTIONS PVT. LTD

NeoMotion is a startup from R2D2 incubated at IIT Madras. It was co-founded by IITM alumni who returned after a short stint in industry to develop the Standing Wheelchair (SWC). In the course of user trials and field visits for the SWC, a need was discovered. Most people were found to be using a one-size-fits-all wheelchair, leading to poor posture and secondary health problems. Outdoor mobility is also limited for wheelchair users since they need help to transfer to a car or a 3-wheeled scooter or tricycle. To address these issues, a wheelchair personalized to a user's health and lifestyle called NeoFly **(Fig. 9)** was designed to provide better propulsion through superior ergonomics, a smaller footprint to make more places accessible, while being aesthetically pleasing. In addition, it was designed to be used with a motorized attachment, NeoBolt **(Fig. 10)** for transitioning seamlessly to outdoor mobility. The startup ecosystem at IIT Madras and the support of the research centre, R2D2, along with funding from various sources - IMPRINT India, HDFC, Tata Boeing Aerospace, Tata Trusts, etc. have made the commercialization of these products a reality after nearly 4 years of R&D. NeoFly and NeoBolt are also products of the GRID model, with the industry partner being a startup in this case.

Fig. 9 : NeoFly

Fig. 10 : NeoBolt

Fig. 11 shows a snapshot of several other ATs developed at R2D2 over the last decade.

CASE STUDIES: ASSISTIVE DEVICES FOR VISUAL IMPAIRMENT FROM ASSISTECH, IIT DELHI

The Assistech is an inter-disciplinary group of faculty, researchers and students at IIT Delhi. The group is focused on developing affordable assistive technology solutions for persons with visual impairment through collaborative and user centered design approach. The primary focus of innovation is on mobility and education, which are fundamental to enable any person to live independently and with dignity. Assistech is actively working for 12 years In this field and its key activities include:

- Identification and validation of AT needs.
- Innovation activities covering need to market-ready product
- Development of business/dissemination models
- Conducting awareness and training programs
- Conducting events which bring together all stakeholders in disability and assistive technology
- Addressing new research challenges in the space of AT
- Collaborating with a large number of organizations working towards empowerment of people with disabilities for larger impact.

The funnel model adopted by Assistech for the journey from need to impact is shown in **Fig. 12**.

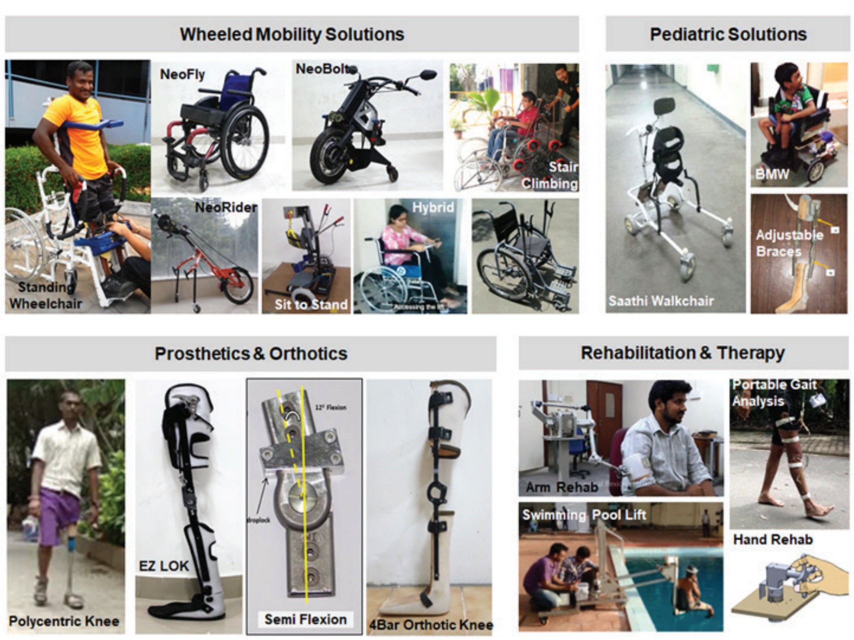


Fig. 11: Prototypes of assistive and rehabilitation devices developed at R2D2 over the past 10 years

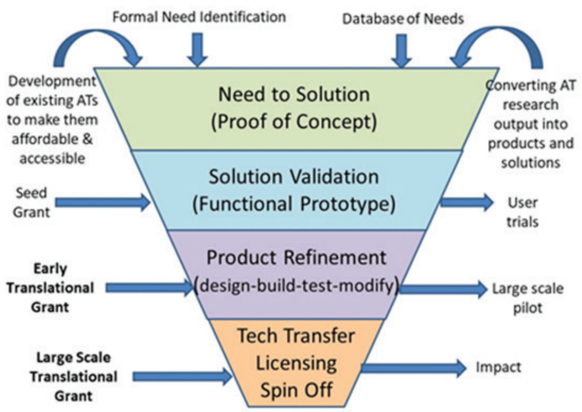


Fig. 12 : Innovation funnel adopted by Assistech

Some of the successful products developed by Assistech Lab are given below.

Smartcane

Smartcane is an affordable electronic travel aid that complements and enhances the functionality of the traditional white cane resulting in improved mobility and safety, and hence reduces dependence on sighted assistance. It employs directional ultrasound-based ranging for obstacle detection and conveys distance information to the user through distinct tactile vibratory patterns.

It is a CE marked and a US FDA approved product which has been in the market since 2015. Approximately 70000 users in India and abroad use this device daily for their independent mobility. Technology has been licensed to Phoenix Medical Systems, which produces this product in their Chennai factory. Technology has won many national and international awards and this product has been chosen for display at Cooper Hewitt Smithsonian Design Museum, New York, Bill and Melinda Gates Discovery Center and Scotland National Museum.

ONBOARD: A BUS IDENTIFICATION SYSTEM

In India and many developing countries, accessing public transport is difficult for the visually challenged due to multiple reasons. A person with visual impairment and blindness can hear a bus approaching the bus stop, but does not know its number. Many times, sighted assistance is not available for these people and there is also hesitation to take help, particularly among women. It is commonly observed that a number of buses arrive together and line up arbitrarily at the bus stop. Thus, even after identification, the user cannot navigate towards the bus since he or she is unsure about its physical location.

To overcome the above challenges, a user-enabled system, called OnBoard has been developed by Assistech to identify the route number of buses approaching a bus stop. The system also provides repetitive auditory cues, enabling the user to navigate towards the entrance. The system has been tested for public buses in Delhi and Mumbai. Large scale implementation of the same is in progress.

Smartcane

Onboard

DOTBOOK - REFRESHABLE BRAILLE DISPLAY

DotBook is an affordable electronic Braille display, designed to enable easy access to digital content for people with visual impairment (VI). Textual content in multiple formats can be accessed through this device. The device has a tactile Braille output interface in the form of raised dots, through which users can access the content line by line. It is developed using an indigenous patented Braille cells based on Shape Memory Alloy technology, which also makes it affordable. The initial funding for development of the first version of Braille cells was provided by DST through their TIDE program. Subsequently significant funding was provided by Wellcome Trust, UK to both develop the product and engaging with industry partners.

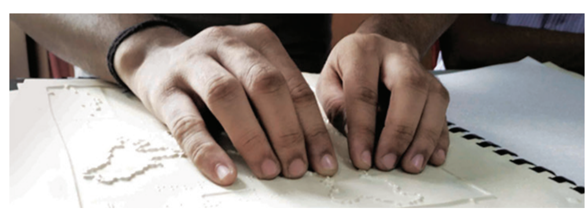
DotBook can be used as a standalone device which can be used to read, write, listen, browse, edit information from multiple sources. It can also be connected to computers, laptops, web, mobile through cable, WiFi, data card, Bluetooth etc. What is a laptop for sighted is DotBook for visually challenged. Development of such a device requires development and integration of multiple technologies which include mechatronics to actuate Braille pins, power management, thermal management, software, hardware interface, interaction design etc. all of which have been incorporated. The product development efforts were jointly undertaken by four organizations IIT Delhi (Academic institution), Phoenix Medical Systems Pvt. Ltd. and Kritikal Solutions Pvt. Ltd., Noida (Industry partners) and Saksham Trust (User centric organization).

Refreshable Braille Display Device

Tactile Diagrams

In this information driven era, the use of pictorial forms of communication has become widely popular but at the same time it is making the world increasingly inaccessible to the visually impaired and blind. Lack of accessibility of pictorial information limits education and employment opportunities for the visually challenged. Tactile diagrams enable perception of two-dimensional images through touch. Tactile diagrams are embossed outline drawings which are specially designed for individuals with visual impairment and blindness in order to communicate visual information. Students with blindness can attempt to study subjects that are heavily dependent on graphics like geography, mathematics, science, etc., if tactile diagrams can be produced in an affordable manner.

A new technology to produce affordable diagrams has been developed by IIT Delhi Assistech Lab. There is an urgent need to take this new and affordable technology to people and society in a scalable and sustainable manner through translation and dissemination. For this purpose, a new Section 8 company, namely Raised Lines Foundation is being incubated at IIT Technology Park in Sonipat, Haryana.



Tactile Diagram

RECOMMENDED ACTIONS

India has to do many things and do them faster if it has to fulfil the promise of empowering all the people with disability through assistive technology. Government and Engineers can contribute to this effort in multiple ways. Following are some recommendations that can be taken up on an urgent basis.

- Initiating research and innovation programs and new centers of excellence for development of affordable ATs. Flexible funding for academic-industry-user partnerships focused on deliverables will enable more industry participation since the risk involved for industry will be low. Programs should provide for enough users to be part of the development process so that the products developed are what users want, and they become the champions for the product.
- Encourage Design and Make in India. The needs of AT for Indian conditions and lifestyles are very different, and therefore development of AT specific to Indian needs must be encouraged. The manufacturing ecosystem needs to be strengthened and working capital loans, especially for hardware startups in AT, will help them achieve sustainability in the long run.
- Co creation of products and solutions involving users and all stakeholders **(Fig. 13)**.
- Working closely with Government, which includes nine national institutes under the Ministry of Social Justice and Empowerment, National Trust, Rehabilitation Council of India, Alimco and disability commissioners of state and central government.
- Promotion of start-ups in the space of ATs and lab-to-market support for budding entrepreneurs in AT space. For hardware startups, setup costs for tooling and infrastructure are very high, so higher levels of support required. Partnering startups with academic labs can help do more robust R&D while cutting costs.

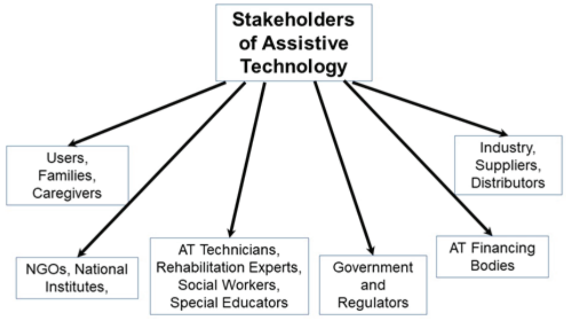


Fig. 13: Stakeholders of AT

- Incentivize and encourage existing industries working in similar areas to take up AT manufacturing. For eg., it is easier for bicycle/ motorcycle manufacturers to set up wheelchair manufacturing.
- Strengthening governmental procurement/ distribution models and development of new pathways including CSR to ensure users get quality ATs of their choice. The government currently has ADIP - the Assistance to Disabled Persons - program, but it is administered only through certain channels, which limits the devices that users can get through the program. Making ADIP a direct benefit program will give AT users more flexibility in choosing an appropriate assistive device of their choice.
- Regular awareness programs for users and training programs for AT personnel, NGOs and others, including new courses and certification programs. Since most devices cannot be directly sold to users and require fitting and training, such programs are necessary to keep the service providers stay abreast of the latest developments in AT and its provision.
- Development of AT resource centers having repositories of AT products. These places will help increase awareness and experience the devices. Knowledgeable clinical support should be a part of these experience centres to help people choose devices that are appropriate for them.
- Establishing and strengthening AT based rehabilitation centers in hospitals. Early adoption of a rehabilitation programme and necessary assistive devices can significantly improve quality of life outcomes for PwD.
- Development of global and country specific standards for ATs, create centralized testing facilities.
- Strengthening regulatory framework for ATs to ensure quality and safety.

- Development of new methods to assess AT products and solutions and training technicians and experts who can assess and certify ATs. Due to the diversity in impairments, determining suitability of a device for a user is very important. Most devices need fitting and training to ensure optimal fit to the user's lifestyle and conditions. This is akin to getting eyes tested at an ophthalmologist before getting the right prescription for spectacles.
- Conducting capacity building programs for AT personnel. Effective involvement of peer trainers can enable awareness to be created more easily and with credibility. Use of tools for remote assessment, simplifying maintenance requirements so that they can be done locally, use of online tools in this age of COVID-19 to continue rehabilitation programs, are all ways to build capacity to ensure every user is reached.
- Development of new technology business incubators for ATs. Startups that are agile and with a clear focus may appreciate better the challenges involved not just in product development but also those in dissemination for this fragmented market, and can be encouraged to adopt a more holistic approach and innovative business models.
- Development of programs and centers to promote universal design. At the heart of inclusion is the development of technologies with increased acceptance and reduced stigma associated with use. Universal design forms the bedrock of this approach, and should be an essential part of the engineering curriculum.
- An improved design thinking approach to address all product life-cycle issues.

CONCLUSIONS

The case studies from IIT Madras and IIT Delhi showcase the possibilities when engineering institutions get involved in the focused development of AT. Both R2D2 (IIT Madras) and Assistech (IIT Delhi) are only about a decade old. Through concerted and collaborative effort, and the support of the Government and other stakeholders in establishing a suitable ecosystem, the assistive device landscape in India can be further transformed over the next decade to make inclusion a reality.

Making available affordable innovations in assistive devices and technologies requires a change in mindset on different levels. Use of appropriate technologies, novel teaching, research and business models are required to address the challenge of inclusion on an impactful scale. Just as suitably designed eyeglasses help us overcome our vision deficiency without making us feel disabled, we need to recognize and ensure that all have access to the devices they need to overcome other impairments as well. This accessibility will enable everyone to perform to their fullest potential with dignity and become meaningful contributors to India and the rest of the world.

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Prof B Ravi is an Institute Chair Professor of Mechanical Engineering at IIT Bombay. He heads the Biomedical Engineering & Technology Innovation Centre, as well as Desai Sethi School of Entrepreneurship. He is well-known for indigenous technology development in metal casting and medical device sectors. Many students and professionals benefitted from his training and mentoring in innovation and entrepreneurship. As board member of several organizations and expert committees of government agencies, Prof Ravi also contributes to project review, policies and practices related to inter-disciplinary translational research and multi-institution collaborative innovation leading to affordable products and social impact.

Medical Device Innovation: Idea to Impact

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ABSTRACT

There is immense potential to develop novel medical devices by identifying unmet clinical needs and leveraging new technologies, leading to social impact through affordable healthcare as well as job opportunities. There are however, several 'valleys of death' between ideation, invention, innovation and impaction. These can be overcome by competent and committed innovators working in conducive and collaborative eco-system. This article describes a systematic process evolved for this purpose at Biomedical Engineering & Technology Innovation Centre (BETIC). Key stages include problem definition by doctors, concept development by researchers, product validation & delivery by entrepreneurs, and deployment supported by investors and other partners. The article also describes the pipeline to identify, train, support and connect aspiring innovators through hackathons, camps, fellowships and exhibitions, respectively. The process and pipeline are illustrated with the real-life story of a multi-disciplinary team who developed a smart stethoscope for remote auscultation of patients in rural health centres by expert doctors in tertiary hospitals. The role of 'running partner' and the relevant best practices including team structure, innovation culture, infrastructure and standard procedures are highlighted. These were adapted by partner institutes (engineering and medical), where many novel medical devices for screening, diagnostic, surgery and rehabilitation were developed, patented and licensed to start-up companies or local industry partners for further commercialization. Their collective experience and insights are expected to be useful to key stakeholders (government, academia, industry and community) involved in building similar eco-systems encompassing research, innovation and entrepreneurship ('RE.INV.ENT') for healthcare and other domains.

Keywords: Biomedical engineering, Healthcare, Medical devices, Product development, Entrepreneurship, Start-up incubation, Innovation ecosystem.

MEDICAL DEVICES

Medical devices and equipment are essential for healthcare. They are used for screening, diagnosis, monitoring, treatment, surgery and rehabilitation of patients[1]. The global market size of medical devices is currently estimated to be over US$ 450 billion per year. They are classified based on the level of risk posed to the life of the patients during their intended use; high-risk devices require more stringent testing and regulatory approvals.

The need for better outcomes (more complete recovery from disease), higher reliability (accuracy and repeatability of diagnosis or treatment), safety (less injury or adverse effects) and efficiency (less time and effort) drives innovation in this field. The devices also need to be affordable, adaptable, available and accessible in countries like India where the per capita expenditure on healthcare is less than 1% of that in USA, which leads global production as well as consumption of medical devices.

It is possible to develop high quality yet low-cost medical devices that are suitable for the local population by leveraging new technologies **(Fig. 1)**. These include CAD/CAE/CAM, 3D printing, medical imaging, image processing, artificial intelligence, machine learning & deep learning, virtual reality & augmented reality, biocompatible materials, tissue engineering, gait analysis, automation, robotics, smart sensors, Internet of Things, Cloud computing, digitization and miniaturization [2].

The market pull coupled with technology push is attracting many researchers and entrepreneurs to this field. They are exploring new directions such as precision/ personalized medicine, patient-specific implants & instruments, hospital automation and telemedicine. These can make healthcare more effective and efficient.

At present, the Indian market of medical devices is estimated to be worth US$ 7 billion (Rs. 50,000 crores) per year, growing at 15% CAGR. About 80% of the requirement is met by imports from USA, Germany and other countries [3]. The local medical device industry is small and fragmented, mostly focusing on low-value products. The companies find it difficult to license novel medical technologies developed in R&D institutes due to high perceived risk coupled with significant lead time, cost and effort for product validation, mass production and market penetration. These challenges are exacerbated by the lack of investors for scaling-up and stiff competition from established MNC brands.

Recognizing the importance of this sector, the Indian government has taken several important steps in the last few years. The regulatory framework has been strengthened through Indian Medical Device Rules, 2017 [4]. The Bureau of Indian Standards (BIS) is adapting global standards for medical device testing. There is increased funding for research and development of medical devices. Innovation and entrepreneurship activities in higher education institutes have been emphasised in the National Innovation & Start-up Policy, 2019 [5] and National Education Policy, 2020 [6] issued by the Ministry of Education. There is a steep increase in the number of relevant courses, conferences and competitions such as Smart India Hackathon. All these initiatives are preparing the ground for rapid growth of domestic medical device industry.

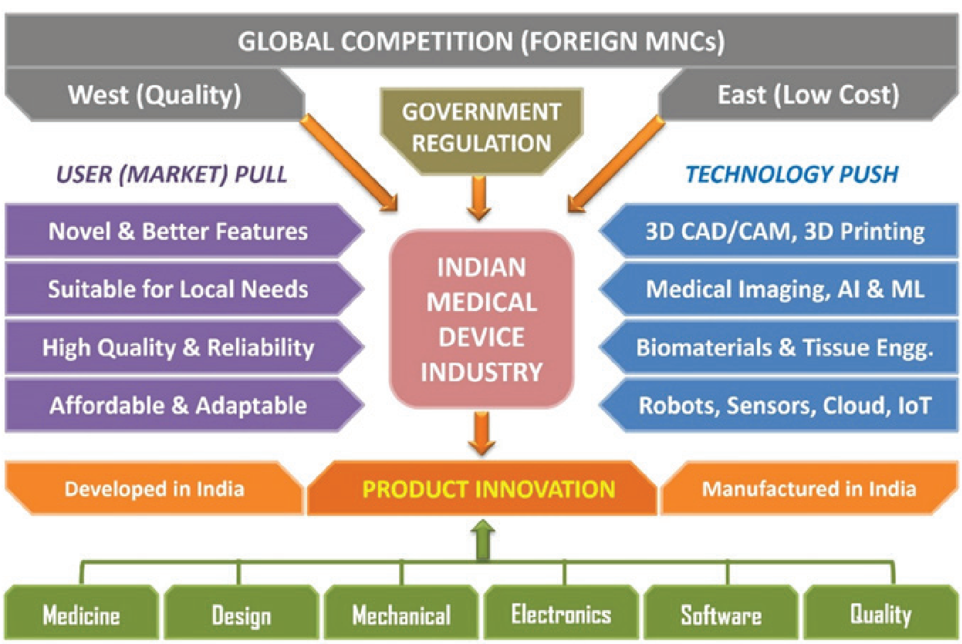

Figure 1 : Medical device industry landscape

INNOVATION PATHWAY

Medical device innovation typically starts from bedside (need identification in hospital), proceeds through bench (product engineering) and business (commercialization) before reaching bedside (application). The importance of need finding is amply highlighted in the 'Identity-Invent-Implement' methodology evolved at Stanford Centre for Biodesign [7], and adopted by many other centres across the world.

Key phases in product lifecycle include conceptualization, rapid prototyping, product engineering, testing, regulatory approvals, mass production and distribution. These require close collaboration among multiple experts from medicine, design, biomaterials, mechanical engineering, manufacturing, electronics, software, quality, management, finance, public health and other disciplines.

Many R&D institutes across the country have taken up med-tech projects funded by various government agencies. However, very few research prototypes get translated into commercially viable products. Those who enter the market, struggle to gain a foothold and to scale up. Most of the medical device projects perish in the 'valleys of death' from concept to market **(Fig. 2)**, which need to be understood and addressed.

Concept to Proof-of-concept (Ideation)

The first step is to identify an unmet need through hospital immersion to observe diagnosis and treatment procedures. Prior art search of publications and patents helps avoid 'reinventing the wheel' and ensure 'freedom to operate'. Then the problem is defined, followed by research to explore new solutions. Proof-of-concepts are developed to demonstrate the core scientific working principles. A large number of such projects are carried out by researchers in medical and engineering institutes, funded by government agencies such as the Department of Biotechnology (DBT), Department of Science & Technology (DST), Indian Council of Medical Research (ICMR) and Ministry of Electronics & Information Technology (MeitY). In most cases, the research work concludes with a publication or patent.

Proof-of-concept to Prototype (Invention)

This includes product engineering (3D computer-aided design and simulation) and rapid prototyping (plastic, metal and electronics) for initial feedback from clinicians. These are facilitated by inter-disciplinary biomedical R&D centres such as SIB, AIIMS & IIT Delhi; School of MST, IIT Kharagpur; HTIC, IIT Madras; BSSE, IISc Bangalore; CfHE, IIT Hyderabad; and ICEM, IIT Kanpur. The relevant equipment, fellowships and prototyping are supported by translational R&D projects funded by special schemes of DBT, DST, MEITY and ICMR for academic institutes. Innovators in bio-incubators and start-up companies can approach Biotechnology Industry Research Assistance Council (BIRAC) for Ignition Grants.

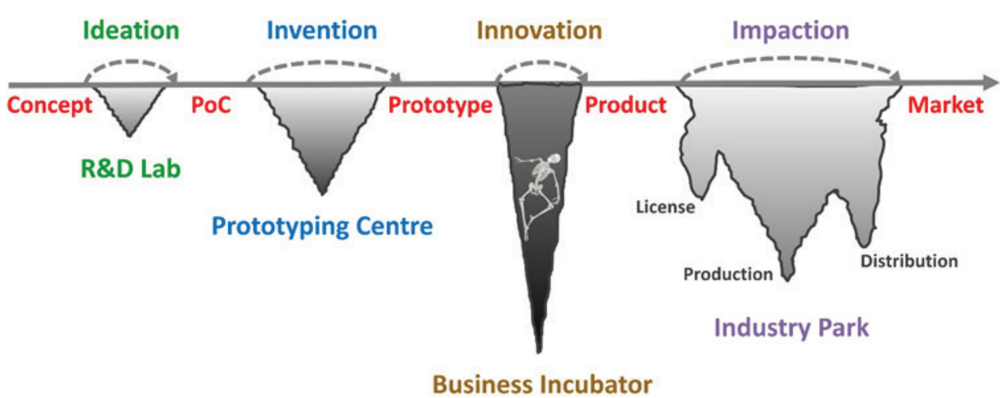

Figure 2 : 'Valleys of death' in product innovation

Prototype to Product (Innovation)

This involves design iterations to improve product aesthetics, ergonomics, reliability and manufacturability. It is followed by medical-grade pilot batch manufacturing and product testing to establish biological, mechanical and electrical safety. Pilot manufacturing has to be carried out in cleanrooms using the same processes as those for mass production later (such as CNC machining, injection moulding and PCB milling). Several bio-incubators have been established in the country, such as C-CAMP Bangalore, IKP Hyderabad, KIIT Bhubaneshwar, SINE IIT Bombay and Venture Centre, Pune. They provide space for entrepreneurs to incubate their start-up companies, as well as common facilities for prototyping and testing. The relevant costs can be covered through various schemes (such as BIPP, SBIRI and PACE) of BIRAC, who have supported over 500 start-ups till date. Most entrepreneurs however, do not possess the necessary knowledge (such as assembly tolerances and testing protocols) to create high-quality and commercially-viable products. Industry vendors refuse to take up such work or charge exorbitantly, since order quantity is small.

Product to Market (Impaction)

After developing and testing a novel medical device in lab, its efficacy and safety has to be established through human clinical trials. This requires approvals from CDSCO, New Delhi, as well as Institution Ethics Committee of participating hospitals. Based on the results, the Drugs Controller General of India (who also handles devices) issues the license for mass production and distribution. The long lead time of human clinical trials and regulatory approvals coupled with the high cost of medical-grade manufacturing and quality assurance are major challenges. This can be overcome by public-private partnership to establish medical device parks with common facilities supported by the government and technical services (at subsidized rates) provided by expert vendors. Plug-and-play parks, such as AMTZ Visakhapatnam established in 2018, will allow small and medium enterprises to quickly set up their production lines and will reduce the entry barriers for indigenous products.

INNOVATION PROCESS

A systematic process of medical device innovation enables successfully traversing the valleys of death encountered in the journey from concept to market. The process was evolved and refined at IIT Bombay over a period of ten years (2010-2020), based on the work carried out at Biomedical Engineering & Technology Innovation Centre. There are four stages: (i) defining a clinical problem, (ii) developing a novel solution, (iii) delivering a tested product, and (iv) deploying it in clinical practice [8]. Each stage is divided into four steps **(Fig. 3)**, briefly described here.

Problem definition: This stage involves (i) building a suitable multi-disciplinary team, (ii) observing clinical procedures to identify an unmet need, (iii) clearly defining the problem, and (iv) evolving a suitable solution concept. The team must include clinicians, who are critical for understanding the problem and later evaluating the solution. Full-time engineers (biomedical, design, mechanical and electronics) are needed to develop the products. Inter-disciplinary experts (such as bio-mechanics and mechatronics) should be available for consultation. The team visits multiple hospitals (public, private, urban and rural) for first-hand insights into the prevailing procedures for diagnosis and treatment. The type, usage, skill-levels and limitations of the current devices are observed. This helps in defining the problem statement, which should include the desired outcome (what), clinical need (why), intended users (who) and location (where). Any constraints (such as size, weight or cost) can also be specified. Then the team generates novel concepts using creative techniques such as bionics, brainstorming and mind-mapping. The concept that has the highest need, value proposition and feasibility is selected for further development. The provisional patent is usually filed at this stage.

Figure 3 : Medical device innovation process (4 stages x 4 steps)

Product Development

This stage involves: (i) product configuration and design, (ii) modelling & simulation, (iii) rapid prototyping, and (iv) functional prototyping. Design implies dividing the product into various components, and deciding their geometric, material and quality specifications. Materials are selected based on the desired physical, mechanical and chemical properties, as well as bio-compatibility, manufacturability and affordability. Powerful software programs available today make it possible to model the products and simulate the operating conditions to predict potential failures, and optimize the design. The simulations are based on many assumptions; hence verified on simple examples and validated by physical experiments. Rapid prototyping includes 3D printing of plastic parts, machining of metal parts and bread-board circuits for electronics. These enable checking the physical form and feel. Then a small number of functional prototypes are fabricated using the same materials as those to be used for mass production later. Clinicians can try them out on cadavers and suggest further improvements.

Product Delivery (Validation)

This corresponds to the third valley of death: translation of research prototypes into marketable products. There are four steps: (i) medical-grade pilot batch manufacturing, (ii) pre-clinical testing, (iii) human clinical trials, and (iv) device certification and licence. The manufacture, assembly, sterilization and packaging have to be carried out in cleanrooms in accordance with ISO 13485. The product is tested on specified equipment as per relevant standards to establish 'reasonable evidence of safety' before human clinical trials. Bio-compatibility tests include toxicity, carcinogenity and skin irritation. Mechanical tests include pull-out, drop impact, water ingress, bending, vibration, deformation, wear and fracture. Medical devices with electronic components are tested for electromagnetic interference and compatibility. The test data and clinical investigation plan are submitted to ethics committees of hospitals and regulatory authorities to permit human clinical trials, which are conducted after obtaining informed consent of volunteers. The resulting evidence establishes the safety (absence of adverse effects) and efficacy (ability to produce the desired result). Diagnostic devices are also checked for sensitivity and specificity – ability to correctly identify those with the disease, and those without the disease, respectively. Finally, the product dossier is prepared and submitted to regulatory authorities (CDSCO in India, CE in Europe and FDA in USA), to obtain the license for mass production, marketing and distribution. The requirements for lab testing and clinical trials increase from low-risk to high-risk devices; for example, the latter require physical inspection of the factory before granting the license.

Product Deployment

This is the final stage where new medical devices reach end-users, and typically involve these steps: (i) securing intellectual property rights, (ii) evolving the business model, (iii) mass production, and (iv) marketing, sales and delivery. These steps are well-known to seasoned entrepreneurs. However, entering the market and gaining a respectable share is very challenging owing to customer scepticism about new products coupled with competition from established MNCs. The IPR (patents, design registrations, copyrights and trademarks) provide legal protection as well as credibility with respect to other companies. The business model is based on the target customers (value proposition), type of offering (standalone device, bundled product, service or hybrid), manufacturing supply chain (from component vendors to factory) and distribution channel (from factory to customers). The innovators can decide to create a start-up company in a business incubator or license the technology to an industry partner. Mass production may be carried out in existing premises, new factory, industry park or contract manufacturing firms. Given that the buyer, payer and user can be different people, the device has to be marketed to the right customer – patient, doctor, hospital, insurance company, government or charitable organization. Mass production and marketing require a high level of financing, typically provided by venture funding and private equity firms. However, they are reluctant to invest in medical device sector owing to the high risk perception coupled with price regulation and long gestation times. As mentioned earlier, this bottleneck can be overcome only by public-private partnerships such as medical device parks with common facilities.

The 4x4 steps described above roughly correspond to Technology Readiness Level (TRL), which starts from ideation (TRL-1) and goes up to commercial launch of the product (TRL-9). Some of the steps or their sequence can vary based on the type of product, starting point and the final goal of the innovation team.

INNOVATION PIPELINE

Innovation pipeline is as important as the process described earlier, to ensure continuous flow of projects through the eco-system [9]. There are four stages in the pipeline set up at BETIC: (i) hackathon to identify potential innovators, (ii) training camp to equip them with the necessary skill-set, (iii) fellowships and facilities to support device development, and (iv) device exhibition for all-round feedback from various stakeholders. These steps take the innovators right up to the 'edge of commercialization' after which they can incubate their start-up companies and later scale-up by moving to an industrial park. These phases **(Fig. 4)** are briefly described here.

Medical Device Hackathon (MEDHA)

They are organized in partner institutes during summer over weekends, allowing local students and young professionals to explore medical device innovation. Each hackathon has 40 participants who form ten teams, each with medical, design, mechanical and electronics background. The teams select projects from a curated list of unmet clinical needs, brainstorm ideas, fabricate proof-of-concepts and present them to a jury panel comprising senior clinicians, researchers and industry experts. The hackathons enable verifying the clinical needs and identifying potential innovators. During 2017-2019, ten MEDHA were organized in various engineering and medical colleges in Mumbai, Pune, Nagpur, Wardha and Kolhapur, involving more than 500 participants and organizers. Most of these institutes later set up BETIC cells.

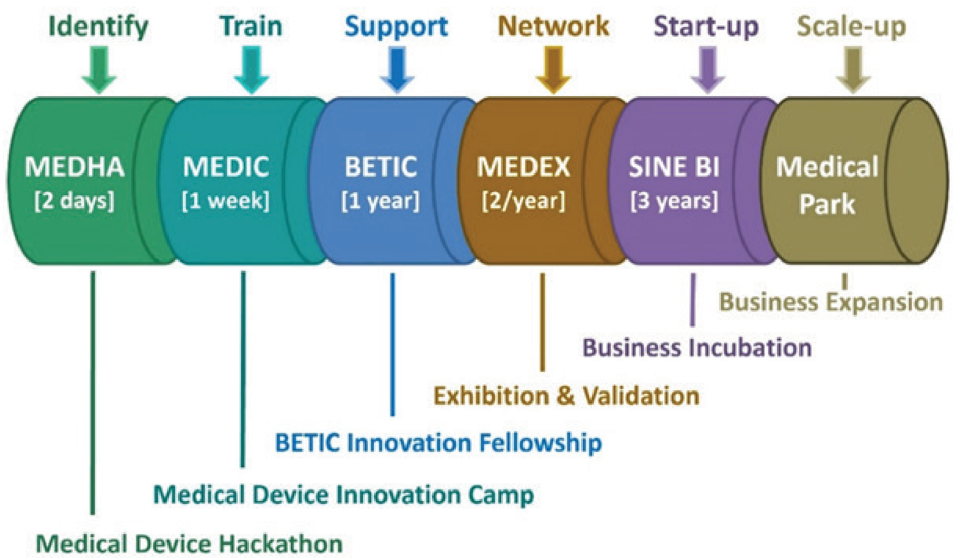

Figure 4 : Pipeline to identify, train and support medical device innovators

Medical Device Innovation Camp (MEDIC)

The camp provides intensive training for committed innovators (identified in MEDHA and similar hackathons), clinicians, industry professionals, entrepreneurs, innovation centre managers and teachers guiding med-tech projects. These are organized at IIT Bombay in autumn over five days. Each camp has 60 participants who form 15 inter-disciplinary teams. They select a project from a curated list, evolve novel solutions and fabricate proof-of-concepts using various raw materials, components and fabrication tools. They also learn about IPR, device testing and regulatory pathway, evolve a business plan, and demonstrate their concept to a jury panel of medical, technical and business experts. Each team has a full-time mentor from BETIC, who keeps their morale high and ensures that they come up with a winning idea and working prototype. The camp also includes lecture sessions by faculty, interactions with domain experts and midnight story-telling by successful entrepreneurs.

Medical Device Innovation Fellowship

The hackathons and camps described above prove to be the turning points ('DNA change') for many participants, who discover their passion for medical device innovation. Such candidates are invited to join as fulltime research fellows to pursue their goal of developing and commercializing a novel product. They leverage the facilities for product design, simulation, prototyping (plastic, metal and electronics) and testing at BETIC, other labs of the Institute and local vendors. The innovation process described earlier coupled with the oversight of senior mentors enables rapid progress from need identification to functional prototyping and clinical feedback. The innovators maintain meticulous records of each step in the process, and report their progress – weekly to other innovators within the lab, quarterly to local expert committee, and annually to national steering & monitoring committee.

Medical Device Exhibition (MEDEX)

Two exhibitions are organized at IIT Bombay every year, one each in April and October, where the innovators showcase and demonstrate their latest products (after securing the intellectual property rights by filing provisional patents). Multiple stakeholders are invited, including engineering faculty, senior clinicians, industry partners, government officials, financial experts and media persons. The innovators obtain all-round critical feedback on various aspects of their product and business model. This helps them to fine-tune the product features, target market and go-to-market strategy. Some of them receive purchase enquiries and partnership proposals. The exhibition is the acid test that tells the innovators if they should take the next logical leap – incubate a start-up company.

Start-up and Scale-up

The above four phases represent the transition from academia to industry. In this context, Atal Incubation Centres, Bio-incubators and other incubators established in R&D institutes across the country play an important role. They provide furnished offices, common facilities (like meeting rooms and prototyping equipment), and access to business, financial and legal experts at subsidized rates. The SINE business incubator at IIT-B incubated over 150 start-ups in the last ten years [10]; incidentally, half of current ventures are in healthcare sector. Once the product is launched in the market and the sales start increasing, the company can expand their operations by moving to industrial clusters or medical parks with common facilities for manufacturing, testing, sterilization, packaging, warehousing and other activities. Alternately, they can license their technology or join hands with suitable industry partners.

INNOVATION CASE STUDY

The story of smart stethoscope module for remote auscultation of patients in rural hospitals illustrates the innovation process as well as the pipeline described earlier.

The clinical problem was posed by a rural hospital doctor Nambiraj, who came to IIT for the Medical Device Innovation Camp (MEDIC) during September 2015. He explained that good auscultation skills (hearing and interpreting heart and lung sounds) are essential to detect cardiac and pulmonary disorders, but require years of practice and experience. Young doctors in rural hospitals often cannot distinguish between different types of chest sounds. Yet they hesitate to send patients to city hospitals due to the expense involved. The doctor wanted to send the chest sound (not the patient) for expert opinion, which was not possible with conventional stethoscopes. Imported digital stethoscopes were available in the market, but were prohibitively expensive. Further, clinicians did not like listening through headphones, which meant losing their identity (stethoscope coiled around the neck), that was essential in dealing with rural patients. Hence the unmet need was defined as "affordable device for remote auscultation of rural patients while maintaining the look and feel of conventional stethoscopes."

The doctor teamed with two other participants – Adarsha and Tapas, both working professionals, with electronics and software background, respectively. Over the next four days and nights, they designed the electronics and fabricated a proof-of-concept guided by Dr. Rupesh, who has mechanical and bio-engineering background. They used a low-pass filter circuit to remove high frequency noise and an amplifier circuit with gain control to improve auscultation sound. During the finale, Tapas transmitted his own heart sounds to the loudspeaker in the hall, impressing the jury panel.

Six months later, both Adarsha and Tapas decided to leave their jobs and joined BETIC to pursue the idea full time. Dr. Rupesh put them in touch with several doctors including Dr. Lancelot, pulmonologist at Hinduja Hospital and Dr. Anvay, cardiologist at Fortis Hospital. Their list of requirements included: (i) sound amplification and noise cancellation for better auscultation, (ii) sound recording and playback for sharing, reference or study, (iii) simultaneous hearing by others for expert opinion without distance barrier, (iv) teaching in medical colleges by wirelessly connecting to speakers and multiple smart phones, and (v) switching between analogue and digital modes to ease the learning curve. The team decided to develop a module that could be fitted between the chest piece and rubber tube (that connects to the earpiece) of conventional stethoscopes. The module would enable physicians to convert their existing stethoscopes into digital ones, and hear amplified sounds from the earpiece (no need for separate headphones). Two models were planned: one with sound amplification, noise cancellation, recording and playback, and the second with above features plus wireless connectivity between chest and ear pieces.

The team designed the product configuration and layout of various components. These included analogue microphone, low pass filter, operational amplifiers, analogue-to-digital converter, switching amplifier, volume control, micro-controller, micro-processor, printed circuit board, memory card, LED, lithium-ion battery, power management unit, on-off button, Bluetooth module (for high-end model), connectors and outer casing. Most of these were procured from different vendors after testing multiple options to find the optimal ones that provided the required functionality and reliability at the lowest cost. The PCB was designed, simulated and fabricated in the lab itself. The enclosure was fabricated by 3D printing for the prototype version, and later injection moulded for pilot batch production **(Fig. 5)**. The team filed a provisional patent in August 2016 [11], and continued to refine the product through many iterations of design improvements, functional prototyping and clinical feedback.

The prototype was tested in many ways to establish its efficacy and reliability. The team created a virtual bench with a frequency generator to test its noise cancelling capability. They carried out drop impact, water ingress and other mechanical tests, as well as electromagnetic compatibility and interference in national accredited labs. The device successfully passed all these. More than a dozen samples were fabricated and handed over to clinicians in different hospitals for use in their daily practice. They were requested to compare its performance with conventional stethoscopes, as well as with imported digital stethoscopes (if available).

During 2016-2017, the device was showcased at medical device exhibitions in Mumbai, Pune and Bangalore where it received good response from both senior and young clinicians as well as industry professionals and other visitors. This gave the required confidence to Adarsha and Tapas for further commercialization. They applied to BIRAC and won the Biotechnology Ignition Grant of five million rupees to kick-start their company Ayu Devices Pvt. Ltd. incubated in SINE, IIT Bombay. The products were named AyuLynk (basic model), AyuSynk (advanced model with Bluetooth) and AyuShare (Android app to store, share, view and analyse the sound files). A dozen engineers were hired to handle design, software, manufacturing, marketing, sales and other functions. They tied up with local vendors to source or fabricate various components, which were assembled and tested within the company. The team and product were featured in many newspapers and magazines, including Forbes India [12] and Outlook Business [13].

One of the first (and later repeat) purchase orders was from the district development officer of Bhavnagar for use in local health centres. In 2018, Ayu Devices team won start-up hackathons organized by state governments Maharashtra and Gujarat, accompanied by purchase orders. More

Figure 5: Smart stethoscope: proof-of-concept, prototype and product

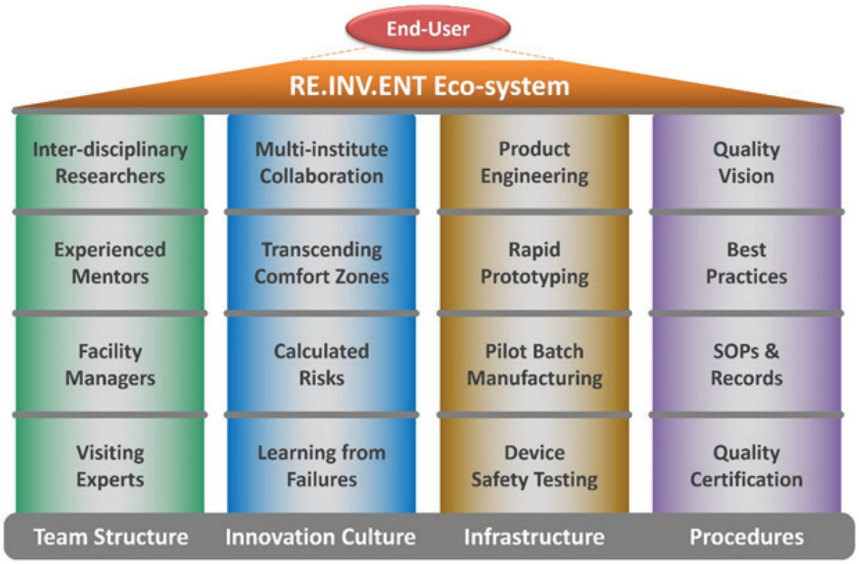

Figure 6: Eco-system for research, innovation and entrepreneurship

awards followed: Swissnex AIT, AI Innovation Challenge, India Innovation Growth Programme and Millenium Alliance. These funds were used to hire more employees, scale up the production and expand marketing activities. The devices were successfully used in rural health camps at Shegaon in Dec 2018 and Chandrapur in Dec 2019 to screen patients for cardiac and pulmonary disorders. By mid-2020, less than three years after its incubation, the company had supplied over 1600 smart stethoscopes to different parts of India and started getting enquiries from Africa, Europe and SE countries. When COVID-19 pandemic struck the country, the Ayu Devices team rose to the challenge and set up smart booths for contact-less as well as remote auscultation of patients, winning them further accolades.

INNOVATION PRACTICES

The Ayu Devices team traversed all stages of innovation process (define-develop-deliver-deploy) and utilized the pipeline (identification, training, support and networking) before incubating their start-up company. The process and the pipeline are two critical dimensions of the innovation eco-system, which helped in minimizing the overall lead time, effort, cost and risk involved in the journey.

There is another dimension of the eco-system encompassing research, innovation and entrepreneurship (‘RE.INV.ENT’). This is related to the best practices involving people, mindset, facilities and systems. These are encapsulated in four pillars: (i) team structure, (ii) innovation culture, (iii) infrastructure and (iv) standard procedures. Each of them comprises four blocks **(Fig. 6)**, briefly described here.

Team Structure

Capable inter-disciplinary researchers committed to developing and commercializing novel medical devices are essential. They are mentored by senior innovators who have successfully traversed the pathway, and know how to integrate relevant knowledge from medicine, design, materials, manufacturing, electronics, quality and other fields. Facility managers must be skilled in efficient operation as well as maintenance of equipment clusters (say, for electronic fabrication and testing). Domain experts (such as regulatory consultants and patent attorneys) are invited to interact with the innovators to fine-tune their products and plans.

Innovation Culture

Medical device innovation relies on seamless collaboration among people from different specializations and organizations, which implies transcending personal comfort zones. They have to take decisions even with ambiguous, incomplete or inaccurate information, then calculate the risks and move ahead. There is high probability of failures, which need to be analysed and utilized to improve subsequent iterations or projects. The work environment has to be intense yet relaxed (not tense and lax).

Comprehensive Infrastructure

Most engineering and R&D institutes have good facilities for product engineering (CAD/CAE/CAM) and rapid prototyping, especially for 3D printing and electronics fabrication. However, there is a severe shortage of medical-grade facilities for manufacturing pilot batches of devices (typically 5-25). Facilities for pre-clinical lab testing to establish biological, mechanical and electrical safety are also limited in the country. The relevant equipments are very expensive and require highly skilled well-trained personnel.

Standard Operating Procedures

The best practices for all tasks that can affect quality (such as operator training, equipment maintenance and device validation) need to be established and continuously improved. The standard operating procedures (SOPs) are documented and records are maintained for future reference. The SOPs help in training newcomers, ensuring high productivity, and minimizing errors & oversights. Once established, the quality management system can be certified for ISO 13484 by accredited agencies. This further enhances the credibility of the team, eases the regulatory pathway for their products, and facilitates technology licensing to industry partners.

Establishing an efficient and effective eco-system with the above elements can only be achieved by unerring and undeterred focus on end-users, especially the under-privileged. This energises the team and attracts the right stakeholders. These insights emerged over a period of five years (2015-2020) when a dozen institutes (engineering and medical) across Maharashtra established BETIC Cells. The main centre at IIT Bombay acted like a 'running partner' for innovators in these Cells. These institutes collected about 400 unmet clinical needs from local hospitals and developed more than 200 proof-of-concepts of different devices through hackathons. The innovators who joined these institutes as BETIC

Figure 7: Medical devices of start-up companies mentored by BETIC

fellows developed over 50 products, filed patents, won BIRAC BIG awards and incubated 16 start-up companies **(Fig. 7)**. The BETIC team also developed many other products (such as biopsy gun, laparoscopy instrument, prosthetic leg and Clubfoot brace monitor) that were licensed to local industry partners; several other products are under development supported by these and other industry partners.

The experience of the BETIC innovators also showed that the total cost, time, effort and expertise greatly increase from low-risk to high-risk products. Devices for screening, diagnosis and monitoring, which help minimize healthcare burden by prevention or early/timely treatment of diseases, fall in low-risk category. Their development, lab testing and clinical trials can be completed in 2-3 years. Medium-risk products such as surgical instruments and assistive devices can take a little longer (up to 5 years). On the other hand, high-risk products (such as articulating implants) can take ten years or more to traverse the entire pathway from concept to market [14]. The eco-system must be able to attract and retain talented researchers over long periods. Building such eco-systems requires long-term commitment and strong collaboration among the stakeholders. These include government, academia, industry, medical community, investors, business incubators, media houses and society.

CONCLUSION

Indigenous development of medical devices has the potential for large-scale social impact through affordable healthcare as well as high-value jobs. It requires a systematic approach for innovation (problem-solution fit) and commercialization (product-market fit). Recent initiatives of the government have created a conducive environment for the academia and industry to come together, form public-private partnerships, and develop novel medical devices to meet the growing demand. The innovation process, pipeline and practices evolved at BETIC enabled successfully overcoming the 'valleys of death' encountered in the pathway. This eco-system has been embraced and adapted by several other institutes to identify and support local innovators. Their success stories of high-quality yet low-cost medical devices are inspiring many others. The enhanced capability and capacity in this important sector will allow import substitution as well as export to other countries in the region who look up to India.

ACKNOWLEDGEMENTS

The support of Maharashtra government through RG Science & Technology Commission, chaired by Padma Vibhushan Dr Anil Kakodkar made it possible to envision and establish BETIC; other government agencies (DST, DBT, BIRAC and ICMR) enabled or encouraged further expansion of the activities. Satellite centres were established and led by Prof A M Kuthe at VNIT Nagpur and Prof B B Ahuja at COE Pune; similar cells were set up in other institutes by committed faculty, making BETIC one of the largest networks of medical device innovation. Senior managers with varied backgrounds and expertise – Dr Rupesh Ghyar, Arun Krishnan, Bharti Dhaundiyal, Glen D'souza, Sagar Talele and Tapas Pandey – dedicated themselves to continuously improving the eco-system and mentoring the innovators. These came from all over India; many gave up 'safe' jobs to pursue the dream of world-class medical devices made in India. Expert clinicians like Dr Manish Agarwal unhesitatingly spent long hours even on weekends with the innovators to explain the problems, explore new solutions and examine the prototypes. The goodwill and support of steering committee members, government officials, institute heads, administrators, colleagues, researchers, industry professionals, journalists and other stakeholders is deeply acknowledged in contributing to the eco-system.

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Author's Profile

Shri Sudhir Garg holds a Bachelor's degree in Electrical Engineering and a Masters Degree in Public Affair from Humphrey school of Public Affair, USA. He has 36 years of experience in Industrial modernization, Infrastructure development, technology related interventions in sectors like Energy, Transportation, Renewable energy etc, and has developed complete policy framework in these areas.

Presently he is the Joint Secretary, Ministry of Micro, Small & Medium Enterprises (MSME) and is working to industrialize rural and semi urban areas through innovation, clustering and integrated approach. Earlier, he headed prestigious programmes of the Ministry of MSME, to develop 'Technology Infrastructure' across the country by setting up Technology centres, at a cost of about Rs 10,000 crores, to support MSMEs, through latest technologies like AI, AR, VR, Robotics, etc. During this period, he was instrumental in reducing the energy bill on Indian Railways by Rs 41000 crores.

In his previous assignment as Executive Director in the Ministry of Railways, Shri Garg was responsible for decarbonisation of Indian Railways by putting up solar and wind power plants, improving energy efficiency, enhanced electrification etc.

His interests include developing future industrial road map for the country, enveloping next generation technologies while keeping environment and manifestations of young minds in forefront

Role of MSME's for a Self-reliant India

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India is a country of 1.3 billion people, who are hard-working, intelligent and sincere to their commitments. In the Golden era we had given 'Zero' to the world, to make Mathematics happen. And in the modern era we are proud of providing the smartest people for most of the futuristic areas including IT sector. Globally, we Indians, have been recognized as highly intelligent and hard-working people. I remember during my Master's program in USA, we the group of four officers was told, 'Oh! Indians, all A+ Grade'. That is what we are now known for. So that is the reputation that we Indians have built for ourselves across the Globe - that we are in the A + category only. So I think, this is the most appropriate time for us to ride on this wave and expand our reach and presence by suitably integrating into high tech areas, to contribute more and more in the global economy.

The call by Honorable PM, on making India Atmanirbhar, is most appropriate and timely. To make it happen, we, have to commit ourselves to strengthen our capabilities further, and to go ahead at a faster pace to attain our place in this dynamic world.

Let us now talk what will it require, to play a bigger role in Global economy and supply chain, with attaining leadership in new emerging areas. Number one item that comes to my mind is developing highly skilled manpower, a manpower which is ready to adapt and learn new things. The second important item is to build the capability to continuously innovate in traditional and new areas. I am happy to share with you that this country is housing more than 1150 Global R&D centers, which shows our capability, as intellectuals. Building upon these areas will make Indian Industry remain competitive and to produce quality products in a cost effective manner.

If we look at how the Western World has grown, then, one of the things we find is that a generation had worked on developing ideas, they loved to work upon. They generated large numbers of ideas across various sectors. They further developed these ideas into solutions in consultation with the industry and mastered the same. Realizing the power of innovation of this highly self-motivated group of innovators, called MSMEs, incomparable to any paid scientist or worker, the industry adopted them as the key intelligent suppliers. This partnership started a chain reaction of new products in every category, in every sector, with large numbers of new cost effective designs and solutions. The strong IPR system made it possible for them to be the owner of all such ideas, which further gave them the incentive to keep innovating and create new and newer products and designs. In the process they became leaders in many sectors.

Taking learning from this model, we will have to move away from the traditional ancillary culture, where the larger industries import technologies and smaller units act as their subsidiary, without much intellectual contribution. Today is the time for us to use our intellect and capability to innovate, which is natural to us, using our educated manpower. This will make it possible for us to create a chain of new products with innovative designs in a cost-effective manner. Understanding this cycle, we need to work like the Hindi film hero, who while chasing the villain, slips down the hill, cutting across all the difficulties, and is able to reach ahead of him, irrespective of the fact that the villain is in a high-speed car or otherwise.

Having realized that skill and innovation are the key components for building and remaining competitive as a whole, let us see what we need to do to make it happen. Few things that come to my mind are – firstly, developing strong linkage between industry, various educational institutions and R&D facilities. Another item would be to create 'Technological Infrastructure' across the country and third item can be adoption of some of the modern engineering practices.

Simpler things first, I will start with adoption of some modern engineering practices. I think we have to take care of some basics first, like adoption of 'Lean manufacturing' practices on a large scale basis across all sectors of Industry, further graduating them into adoption of IT-based integration of various activities, now known as industry 4.0. I would like to share a story on benefits of implementing 'Lean'. Last year, in December, I was in Pune where I was talking to a group of industries, mostly from the MSME sector. On my enquiring about following of 'Lean practices', few hands rose. One gentleman said that after implementation of 'Lean', his mobile phone which used to keep ringing earlier has now stopped ringing. The implementation of Lean streamlined all the processes including the chain of command in his factory. This made it possible for him to devote more time in exploring new markets, new technological and financing solutions etc. This is one movement which we need to bring to all our work places to change the way we work.

I would like to bring out here that the Ministry of MSME, as part of supporting 'Lean manufacturing' practices, provides up to 80% subsidy to MSMEs. This one single act can lead to reduction in costs up to 30% easily. Adoption of these practices will take our work force on the 'Growth mind set'. This will also act as the foundation in our adoption of industry 4.0 practices.

The need of the hour demands eminent engineers to come forward and create various groups to bring in this cultural shift in our industries, both in manufacturing and service sectors.

The second pillar of building competitiveness is to create strong linkage between industries, educational institutions and various R&D facilities. For this we need to set up large number of 'centers of excellences' covering variety of areas, with technical institutes, like IITs, NITs, other engineering colleges etc. The technical institutes, using the talent of youth in their institutes and by joining hand with various R&D institutes, in respective areas, shall provide low cost innovation and solutions to the industry.

I would like to share here an experiment which we did in few industrial cities in Maharashtra where around 20 engineering colleges came forward and agreed to take up 200 industry problems. They, with the help of around 600 students worked on these problems. Initially the industry was of the view that connecting with these institutes, many of which were from the private sector, will not be of any great use for them. But you will be happy to know that now the MSME Associations in Maharashtra are so happy and gaga about this initiative that they want to expand this program across the state of Maharashtra. In this process few students generated IPRs and have already started their businesses. We are working to take it to other states as well like Punjab etc. So the learning is simple. We have to work to bring out this intellectual capability of Indian fertile minds, through Industry-Institution Connect, to benefit our businesses.

The Ministry of MSME is working to set up number of centers of excellences with IITs, NITs, etc. We recently opened one such center in IIT Madras, to develop new technologies and products for the Coir sector. This sector is exporting materials worth Rs. 2800 crores annually and has plans to increase it to Rs. 10,000 crores. The key to it is to go for 'value addition' to the products being exported now.

The Ministry through its scheme called 'Gram Udyog Vikas Yojna' is now working to support traditional industry by making them modern and cost-effective. We are setting up large number of clusters across the country for supporting the traditional industry which has huge potential to go up to one lakh crores turn over in a decade. For such traditional areas too like, Honey, Pottery, Agarbatti making etc., we setting up more CoEs with IITs, NIITS etc. The Ministry of MSME is having another center of excellence with IISC Bangalore for high end products. Other wings of Government of India, like the Ministry of Heavy Industries, Ministry of Textile, Ministry of Science and Technology and other Ministries are also working to expand their linkages with various institutions in the country.

The third item for building our competitiveness is developing 'Technological infrastructure' across the country. We all know that, if the infrastructure is in place, then the development happens much faster. For developing highly skilled manpower and to build capability to continuously innovate, our youth needs a place where they can give shape to their ideas. For this purpose the Ministry of MSME is working to create large numbers of technology centers as 'Technological Infrastructure' across the country. As you may be aware that the Ministry had been running around 18 technology centers for quite some time and is now setting up 15 additional centers at a cost of around Rs. 3000 crores. Many of these centers have already become functional, though with partial facilities. In addition 120 more centers are being set up, taking the availability of this infra, up to district level, at a cost of around Rs 6000 crores. These centers will provide industry with highly skilled manpower and along with the facilities to develop low cost solutions to their current challenges. These centers will also work with industry to develop solutions for their future needs by exposing them with new technologies like AI, AR, VR, Robotics etc. In addition following the cluster approach, common facilities, with latest technological interventions, are being created in large numbers for small and micro sectors. These facilities will form the backbone of the technological infrastructure for industries to bring down their costs and innovate new product lines.

Further, the Ministry of MSME and other Ministries of GoI are setting up incubation centers in various institutes. These centers provide financial support to incubaties for developing their ideas and thereafter developing their business around such proven ideas. These centers will act as building blocks to channelize their energy, intellect and ambition to continuously innovate in this world of technological disruptions. The new National Education Policy, announced recently, will further give boost to building on skilling and innovation capacity of our youth, from the beginning.

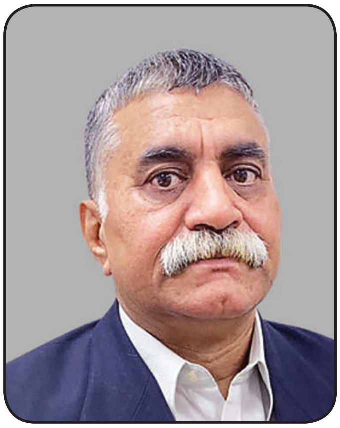
The Institution of Engineers (India) and its various chapters can partner with such programs, some of which provides financial assistance up to Rs 10.0 crores, and develop incubation centers in each of their centers.

Today this country is developing fast, not only the urban landscape, but also in rural areas at an even faster pace. This growth in villages is bound to increase with hundred percent digital connectivity, which is likely to happen soon, as recently announced by our Honorable Prime Minister. This will open up large number of business opportunities. There will be a need to create various solutions of which many may be unique to Indian needs. This may provide impetus to develop so many low- cost solutions in various areas like, services integration, e- mobility, health services, education etc. The Ministry of MSME has a scheme called Prime Minister's Employment Generation Programme under which we are receiving more proposals to set up industries in micro sector, in the current financial year despite disruptions due to pandemic, as compared to the previous year. This shows the growth potential in villages and semi urban areas.

For capturing bigger pie of the global market one need to simultaneously concentrate on new and emerging areas. This will allow us to become global leaders in at least few areas. The probable areas may include sustainability, green manufacturing, waste to wealth, re-manufacturing, solutions for distributed living, development of smart villages, additive manufacturing, e- mobility, AI, Robotics, VR based solutions etc.

The industry leaders control a few out of five key components of manufacturing cycle, which will include demand assessment for a product, designing the same, financing the manufacturing, manufacturing the product, and finally marketing it. We will have to therefore work now in new and emerging areas to attain leadership in some of the five components in these new areas.

I would like to end with a clarion call to the entire engineering fraternity comprising of distinguished seniors, contemporaries and young engineers to act as mentors, and share their knowledge & experiences with large number of people in the country, who want to use their enterprising capability, and the zeal to ride on 'Disruptions' to change future for themselves, and of their Nation.



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Attaining 450 GW Renewable Power by 2030

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BACKGROUND

Ahead of the 21st Conference of Parties to the United Nations Framework Convention on Climate Change (UNFCCC) in Paris in December 2015, India submitted its Nationally Determined Contributions (NDCs) to the UNFCCC, outlining the country's post-2020 climate actions up to 2030 and committed to increase the country's share of non-fossil-based installed electric capacity to 40 percent; reduce GHG emissions intensity per unit GDP by 33 to 35 percent below 2005 levels, and to create an additional carbon sink of 2.5 to 3 billion tonnes of carbon dioxide through additional tree cover.[1] Increasing renewable energy electric installed capacity to 450 GW by 2030 is a part of plans for meeting India's commitments.

As of 2019, India consumed 5.8 percent of the global commercial energy and electricity. Coal had largest share in the commercial energy (54.6 per cent), followed by oil (30.1 percent); Natural Gas (6.3 per cent); hydro power (4.2 percent); modern non-hydro renewables (3.6 per cent); and nuclear (1.2 per cent).[2] There is no authentic data source to quantify the non-commercial energy such as charcoal, fuelwood, animal waste and straw – used mainly for cooking. However, IEA's broad level data suggests that share of these sources has decreased significantly over the years, and constitutes around 20 percent in the primary energy mix. In the year 2018, India's per capita CO2 eq emission from energy related activities was 1.71 tons/capita, about 38 percent of the world average.[3] In absolute terms India's share in global CO_2 emissions was only 6.8 per cent of the global emission.

India has an installed grid connected power generating capacity of 373 GW (30 September 2020).[4] Thermal power (from coal, natural gas and diesel) with 231 GW comprises 62 per cent of total installed capacity followed by renewable energy (wind, solar, small hydro, biomass etc) with over 89 GW (24 per cent), large hydro with a contribution of 45.7 GW (12.3 per cent), and nuclear with over 6.7 GW (1.8 per cent) make up the rest. Since the year 2017, the annual renewable energy capacity addition has been exceeding the addition of coal based thermal power and at present around 76 GW renewable energy capacity is under implementation.

RENEWABLE ENERGY – FRAMEWORK AND STATUS

Electricity is a concurrent subject under the Constitution of India, and Centre and States can both legislate on this matter.[5] Matters relating to inter-state transactions are in the Centre's domain while states are responsible for the intra-state sale, purchase, distribution and supply of electricity. Electricity Act 2003 and its emanating

1. http://www4.unfccc.int/submissions/INDC/Published%20Documents/India/1/INDIA%20INDC%20TO%20UNFCCC.pdf
2. BP Statistical Review of World Energy 2020
3. IEA: Key World Energy Statistics 2020
4. Ministry of Power, https://powermin.nic.in/en/content/power-sector-glance-all-india
5. Under the quasi-federal constitutional structure of India, the legislative and executive powers are delineated between the Centre and states. The Seventh Schedule of the Constitution designates subjects over which the legislative power is assigned to the Center (List I), states (List II), and concurrently to both (List III).

policies provides the regulatory framework for renewable energy development in the country. The Act empowers State Electricity Regulatory Commissions (SERCs) to ensure that a percentage of total consumption of electricity originates from renewable energy sources. The Act also empowered the SERCs to specify the terms and conditions for the determination of tariffs. Policy instruments such as the National Electricity Policy (NEP) and the National Tariff Policy (NTP), as revised from time to time, guide the governments and regulators at both the central and state levels, on various aspects of renewable energy policies, programmes and also tariff determination.

Over the period, renewables have transitioned from niche acts to major contributors in the electricity mix. The existing policy and regulatory provisions including uniform renewable energy purchase obligations across the States/UTs have created an assured market and enabled long-term contracts and financing for renewable power projects. The government of India's promotional measures have successfully addressed many of the structural challenges. Waiver of interstate transmission system charges and losses for sale of power from solar and wind power projects have helped in optimal harnessing of best renewable resource locations, thereby reducing the cost of the power. Competitive bidding of solar and wind power has led to standardization and uniformity in the procurement process. Continued focus on improving dispatchability of renewable power has yielded encouraging results. Solar and wind power projects, either in hybrid form or in conjunction with energy storage systems, have been successfully bid out and would provide firm power during peak hours and/or pre-determined durations.

OUTLOOK 2030 AND BEYOND

India has declared aspirational goal to reach a target of 450 GW by 2030. This is primarily based on findings of the Central Electricity Authority (CEA) study that has estimated electric installed capacity and electricity generation at 817.2 GW and 2518 GWh respectively, by the end of 2029-30. The generation capacity would comprise of 292 GW from thermal, 17 GW from Nuclear, and 430 GW, amounting to 52%, from non-hydro renewable energy. Absorption of non-hydro renewables into the grid will require battery energy storage capacity of 27 GW/108 GWh. The study report further states that renewable energy generated will not be fully absorbed into the grid and the curtailment range from nil on minimum RE generation day, to 14.6 per cent on maximum RE generation day.[6] **(Table 1)**.

Although the CEA report is technical in nature and the analyses have been undertaken at the macro level, it gives a fairly good assessment of the direction in which India's power sector

6. CEA- Optimal Generation Capacity Mix for 2029-30

Table 1: likely Installed capacity and electricity generation by the end of 2029-30

	Capacity		Generation	
Source	**GW**	**Percentage Capacity**	**GWh**	**Percentage Generation**
Hydro (including imports)	66	8.1	207	8.2
Pump Storage	10	1.2	4	0.2
Coal	267	32.7	1393	55.3
Gas	25	3.1		
Nuclear	19	2.3	113	4.5
Solar	280	34.3		
Wind	140	17.1	801	31.8
Biomass	10	1.2		

is moving. The share of thermal power installed capacity and generation in the electricity mix is progressively declining and the upward trend of non-fossil fuel power led by solar and wind is to continue. India's energy outlook from various analyses are also on the similar lines. IEA outlook 2030 suggests energy demand growth by an average of 2.6 per cent annually through to 2030 and Solar PV growth meeting 10 per cent of all primary energy demand growth to 2030.[7] British Petroleum outlook 2050 suggests that in the business as usual scenario India would account for 35 per cent of the increase in global primary energy consumption during outlook period, and witness intense renewable energy growth in the range of 9-13 per cent per year.[8]

CHALLENGES IN ATTAINING 450 GW BY 2030

The global trends and projections clearly indicate that the share of renewable energy would continue to increase in the energy mix. The cost of electric power generation from renewable energy sources, in a large number of situations, has already become competitive to the cost of thermal power generation. Price discovery in recent tenders gives an assurance that renewable energy installed capacity by 2030 would be within reach.

However, achieving this target will be confronted with structural, regulatory and institutional challenges including the poor financial conditions of many state distribution companies, access to finance, land acquisition issues, and integrating variable output renewables with the grid. Increasing share of renewables brings along grid stability concerns. In some of the renewable resource rich states renewable energy curtailment is regularly resorted to for preserving grid security. Thermal power plants are required to operate flexibly to balance the variability of renewables, which also adds an additional cost. Integrating higher share of renewables in the electricity grid would require significant investment for augmenting the transmission infrastructure, adding energy storage and other measures for strengthening and enhancing flexibility of the grid. Availability of cost competitive dispatchable renewable energy would be a necessity in the long term.

A major hurdle has arisen from a mismatch in the projected demand and supply capacity. The pace of electricity generation capacity additions has far exceeded demand growth. There is also a mismatch between incentives for generators, which require attractive payment guarantees to safeguard investments in capacity developed under central or state agency auctions, and the Discoms on the receiving end, which primarily off take this new capacity for fulfilling RPOs and have to bear the additional costs for integration. As such, the Discoms supply power to a large section of consumers at tariffs below the pooled cost of purchase, and struggle to achieve revenue goals. Further, the electricity pricing regime dis-incentivises the generators willing to sell power in market.

AGENDA FOR ACTION

As the pace of renewable energy capacity addition continues to exceed demand growth, the long-term thermal power purchase agreements would need to be unlocked. With excess power generation capacity, declining renewable energy prices, and increased competition would make short duration PPAs, say 7 years' duration, an attractive option compared to long-term ones.

Conventionally, PPAs for thermal power are modelled around fixed cost recovery principle. Lower PLF, as a result of increasing share of renewable, may not lead to financial distress as fixed costs continue to be levied on the purchaser. However, the frequent and faster ramping required to accommodate short term variability of renewables is likely to have cost implications and requires technical upgradation. Regulatory provisions for compensating flexibility services by thermal power plants will be critical for larger

7. IEA: World Energy Outlook 2020
8. British Petroleum Outlook 2020: online: https://www.bp.com/content/dam/bp/business-sites/en/global/corporate/pdfs/energy-economics/energy-outlook/bp-energy-outlook-2020-country-insight-india.pdf

uptake of renewables. CERC or SERCs may address this issue and could specify additional tariff on this account.

Augmented distribution networks and energy storage planned optimally at both transmission and generation ends will be essential for addressing the solar energy induced daily duck curve and to keep up with the seasonality of the wind power generation. In addition to energy storage, enhanced regional interconnection with ultimate objective of seamless integration of all India power system would be necessary. Already a beginning has been made with renewable energy management centres and 'green energy corridors' across eight renewable rich states, for evacuation of renewable power to the load centres.

Ideally, with declining cost of solar power, India should accelerate deployment till it matches the peak day time demand. At that stage, thermal power plants could operate in shifts. For day time imbalances gas fired plants, in addition to hydro, could meet the balance requirement. To be effective, such a generation scenario needs to be coupled with 'time of the day' electricity pricing by Discoms, to begin with for industrial and commercial sector. This will incentivise shifting of energy intensive operations to day time when low cost solar power is available. Looking at projections for declining energy storage cost, in the initial years India could focus on absorbing maximum solar and wind power with minimal storage requirement. The current focus should be towards acquiring cutting edge energy storage technologies and creating indigenous manufacturing, ultimately leading to drastic cost reductions and enhanced uptake. India's National Mission on Transformative Mobility and Battery Storage has been envisaged with these very objectives.

However, while the manufacturing capacities are being planned and costs remain high, controlled deployment of energy storage systems for gaining field experiences would be necessary. Towards this end, the focus on innovative bids for supplying dispatchable power from renewables should continue. This will provide an option to State Discoms to meet their power demand either by thermal or renewables on demand. Similarly, deployment of other emerging technologies such as hydrogen energy, which could potentially enable penetration of renewables in a wide range of economic sectors, would need to be undertaken.

Further, strengthening the merchant power market will help in increasing the share of renewables in cost effective manner. Real time power market, launched in June 2020, has provided real time corrections for both renewables as well as the demand. The green term-ahead-market (GTAM) launched in August 2020, has allowed selling of power by the renewable developers in the open market without getting into long term PPAs. This has also helped in achieving renewable purchase obligations, meeting short-term demand at competitive prices, and also granted a window for generators and Discoms for selling excess power and avoiding curtailment.

While the developments are encouraging, and generation costs are falling rapidly, there are still a number of major policy and infrastructure reforms that need to be accomplished to make renewable energy competitive in open market. The challenge is to meet the dual objectives of higher renewable energy share and keeping the consumer tariffs low in the face of slow growth in demand. Left to its own devices, the markets would pull down the renewable power growth trajectory below what is required to achieve our ambitions of 450 GW. It is therefore imperative to continue to support renewables both through some form of affirmative action to ensure sufficient demand and encouraging technological interventions to make renewable power quality competitive with other alternatives on the market.

Renewable energy goal for 2030 would translate into an investment opportunity of around US$ 15-20 billion per year. Ensuring payment security and tackling the risks related to delays in payments to independent power producers would be necessary for earning investors' trust. A beginning has already been made and Discoms have been mandated to issue and maintain letter of credit. Bond market, which assures a constant and low risk yield for renewable energy deployment, would need to be further explored. Other areas for action include low-interest rate, long-term international funding and developing a suitable mechanism for managing currency hedge risk.

INDIGENOUS MANUFACTURING

Deployment of 450 GW renewable energy electric installed capacity by 2030 does not translate into energy security for India. The solar power sector lacks a complete indigenous value chain, and nearly the entire demand of solar cells is met through import. At present, while India has around 16 GW operational solar modules and 3 GW of solar cell manufacturing capacity, a significant portion of it remains underutilized, as the domestic manufactures fail to compete with aggressive pricing and rapidly improving performance capabilities the imported solar PV cells and modules. There is no commercial production for upstream stages of polysilicon and wafers in India. In 2019, net import of solar PV systems in the country was around US$ 2 billion **(Table 2)**.[9]

The general impression is that solar energy manufacturing in India lacks a level playing field as compared to competing nations which have access to heavy subsidies and other incentives for large scale manufacturing. This is further compounded by inherent domestic disabilities such as high cost of finance and commercial electricity, and other infrastructure bottlenecks. An article published in the Business Standard on 5 December 2020[10] quoting data from the Ministry of Commerce, Government of India states that "Chinese solar equipment imports jumped nearly six times in 2013-14 when tenders for solar power projects were gathering momentum in India. Till 2017-18 imports grew steadily, tapering 24 per cent after 2018, under the combined impact of safeguard duty and slowdown in award of solar projects. Analyst reports show that China has reduced benchmark price of solar photovoltaic panels by more than half to a global low of US $ 0.15-0.20 per kWh in the past eight months."

Table 2: India's import and export in Solar PV systems (in million US$)

India Solar PV	Year		
	2010	2015	2019
Export	945.15	112.9	202.3
Import	551.06	1889.2	2089.2

In December 2011, India announced the National Manufacturing Policy (NMP) that aims at increasing the share of manufacturing in GDP to 25 per cent within a decade. Its two major objectives are to increase domestic value addition and technological 'depth' and to enhance global competitiveness of Indian manufacturing through appropriate policy support. It specifically refers to renewable energy at many places in the context of industries with strategic significance, technology acquisition and development, and special focus sector.[11] In pursuant, in June 2012, the Department of Industrial Policy & Promotion (DIPP) established a Technology Acquisition and Development Fund (TADF) to buy and acquire technologies either nationally or globally. It had specific mention of equipment and/or technologies used to produce energy from the sun, wind, geothermal and other renewable resources. Later in 2016 this scheme was transferred to Ministry of Micro, Small & Medium Enterprises.[12] The 2007 Special Incentive Package Scheme (SIPS), later modified, as part of the Semiconductor Policy with an aim to provide boost to the semiconductor manufacturing sector had also included solar PV.[13] However, these efforts could not take off

9. Source: UN Comtrade HS 854140 (Photosensitive semiconductor devices, incl. photovoltaic cells whether or not assembled in modules/made up into panels). Comtrade provides international merchandise trade statistics for 170 countries. It is based on HS classification system. HS 854140 : https://comtrade.un.org/data/
10. Business Standard, Delhi, Shreya Jai, 'A power gap for RE players' 5 December 2020
11. National Manufacturing Policy; Ministry of Commerce 2011 online: https://www.meity.gov.in/writereaddata/files/National%20Manufacturing%20Policy%20(2011)%20(167%20KB).pdf
12. https://dipp.gov.in/sites/default/files/Annexnmp2.pdf
13. Ministry of Information and Communication Technology : online: https://www.meity.gov.in/esdm/incentive-schemes

and were unsuccessful in creating full value chain of indigenous manufacturing in the PV sector. Situation is far better in wind and other renewables where significant indigenous capacities have been developed to build systems, components and sub-components.

The Government of India's keenness for domestic manufacturing is reflected in a number of recent initiatives and promotional measures. On the demand side, about 40 GW domestic content requirement for solar cells and modules has been created under programmes like CPSU Scheme Phase-II, PM-KUSUM Scheme, Rooftop Scheme Phase-II etc. Safeguard Duty has been imposed on imports from some countries. In November 2020, the Union Cabinet approved Rs 4500 crores under production linked incentive scheme for high efficiency solar PV modules. However, the challenges lies in addressing the fundamentals to encourage manufacturing at scale, particularly, access to critical raw materials, electricity at rational rates, enabling infrastructure, continuity of policy initiatives, focus beyond domestic markets, and linkages with innovation system for resource acquisition, technology development, and process upgradation.

GLOBAL THRUST FOR RENEWABLES

India's renewable energy aspirations are part of global thrust for achieving improved energy access, energy security and mitigating climate change. As per Renewables 2020 Global Status Report by the end of 2019, nearly all countries had support policies in place for incentivising renewable energy, although with varying degrees of ambition, scope and comprehensiveness.[14] Jurisdictions have adapted policies to meet their specific circumstances, including support to increasing renewable energy capacity and generation, to boost job creation, and to increase energy access and security. Policy instruments included solar mandates, feed-in pricing, net metering (and virtual net metering), renewable power procurement, including through PPAs, renewable energy certificates, utility-led procurement programmes and self-generation. These apart, the policy push for systems integration of renewables and enabling technologies, such as energy storage, remained focused on increasing power system flexibility and control, as well as grid resilience. Policies to advance the integration of renewables included market design, demand side management, transmission and distribution system enhancements, grid interconnections and support for energy storage.

CONCLUSION

Key drivers for accelerated deployment of renewable energy have been strong policy focus coupled with global decline in costs. These developments are indicators of ongoing energy transition with three main components – progressive phasing out of fossil-fuel; intense electrification of many more sectors of economy; and decentralization of the energy systems. However, for India success will depend on mobilization of the necessary finance and investment on competitive terms; creating an innovation and manufacturing eco-system in the country; economically integrating larger share of renewables with the grid; enabling supply of firm and dispatchable power from renewables; and enabling penetration of renewables in the so called hard to decarbonize sectors.

On 1 February 2019, the Finance Minister laid out the government's vision for India in 2030, highlighting '10 dimensions'. He stated "Making India a pollution free nation with green Mother Earth and blue skies is the Third Dimension of our Vision. This India will drive on Electric Vehicles with Renewables becoming a major source of energy supply. India will lead the world in the transport revolution through electric vehicles and energy storage devices, bringing down import-dependence and ensuring energy security for our people." This set a clear policy signal for accelerating development and deployment of renewable energy.

14. Renewables 2020 Global Status Report: https://www.ren21.net/wp-content/uploads/2019/05/gsr_2020_full_report_en.pdf

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Author's Profile

Shri Rakesh Kumar Upadhyay is an Indian Telecommunications Service (ITS) -75 batch officer. He held the positions of Chairman cum Managing Director (CMD) of two leading Telecom PSUs viz Bharat Sanchar Nigam Limited (BSNL) and Telecommunications Consultants India Limited(TCIL).

A graduate of IIT, BHU, Varanasi in Electronics Engineering,he is also a graduate ofDefense Services Staff College(DSSC) Wellington. He was awarded MSc(DS) degree by Madras University and is a MBA from IGNOU.

He served telecommunications sector for nearly 40 years in India and abroad and held important positions in the Department of Telecommunications(DOT),Government of India,TCIL and BSNL. He successfully led these two PSUs as their Chairman and Managing Director(CMD).

He also served as country in-charge Republic of Yemen(ROY) and People's Democratic Republic of Algeria for TCIL. He has attended various training programs, conferences in India and overseas. A widely travelled person, he headed and also was member of important Government delegations visiting foreign countries. He delivered keynote addresses in many international conferences.

Positions held currently:

1. Member, Telecom Advisory Board of Power Grid Corporation of India(PGCIL)

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5G- A new Generation Wireless Technology: It's Potential on India's Socio-Economic Growth

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INTRODUCTION

5G, the next generation of cellular mobile technology promises significant enhancement in speed, coverage and responsiveness of wireless access networks. Speeds of >1 gigabit per second have already been demonstrated which is ten to hundred times faster than fastest of previous generation of cellular networks. Deployment of 5G networks is expected to usher in an era of ubiquitous, high-capacity low latency radio paving way for a host of cutting-edge technology application in multiple sectors of economy spurring/giving much needed impetus to the socio-economic growth. 5G has the potential for being a transformational force and will be discussed in following paragraphs.

CHARACTERISTICS AND STATUS OF INDIAN TELECOM

With 117.797 crore telephone subscribers (as on 31.03.2020: source TRAI report), India is world's second largest telecom market. It is characterized by strong consumer demand and liberal and reformist government policies. Market is dominated by wireless (mobile) subscribers which account for 98.28%of the total subscriber base. Whereas urban tele-density (no. of telephone per 100 population) stood at 142.31%, rural tele-density is only 58.79% depicting yet another case of urban-rural divide in the sphere of development of the nation. Efforts are continuously on to connect 'unconnected-areas' to bridge the digital divide.

HISTORY OF WIRELESS NETWORKS IN INDIA

A phone call was made on 31st July 1995 between Writer's Building, Calcutta (Now Kolkata) and Sanchar Bhavan, 10 Ashoka Road, New Delhi; that changed, the way Indian's communicate, forever and ushered in the Telecommunications revolution in the country. What was different / special? It was first time that a mobile phone call was made. Dignitaries making and receiving the inaugural mobile call were erstwhile Chief Minister of West Bengal Shri Jyoti Basu and the then Union Telecom Minister Shri Sukh Ram. Mobile phone handsets were Nokia make and Network was based on GSM Technology; company being "Modi-Telstra "(A joint venture between B K Modi Group and Australia's Telstra, later branded as Spice). Though network was primitive compared to what we have today but was totally devoid of congestion! It's another matter that back then both incoming and outgoing mobile calls were charged @Rs 8(approx.) per minute in off-peak traffic time, peaking to Rs 16 (approx.) per minute. We have really come a long way where on a state of art 4G LTE network, voice calls are free!

- Early deployment was based on 2G technology (primarily voice services, slow speed internet in 2.5 G-GPRS, EDGE). GPRS: General Packet Radio Service. EDGE: Enhanced Data for GSM evolution.
- 2010: First 3G technology-based service

launched (Mobile Broad Band wireless access introduced: email, video, social media)

- 2016: 4G launched (high speed data services like HD video etc. in addition to voice)
- 2021: 5G launch (Expected)??

However, for records sake, it must be mentioned that first experimental Wireless Telegraph (WT) link was established in Kolkata as back as 1902 with routine use (of WT) commencing in 1908 in Diamond Harbor; also, in 1985 first mobile telephony was launched, though on-non-commercial basis, based on DECT (Digital European Cordless Technology).

EVOLUTION OF MOBILE STANDARDS

Global System for Mobile communications (GSM) was developed to carry voice services in a circuit switched manner. Data services were also possible over a circuit switched modem connection but with very low data rates. The first step towards an Internet Protocol (IP) based packet switched solution was taken with the evolution of GSM to General Packet Radio Service (GPRS), using the same air interface and access method.

To reach higher data rates in Universal Mobile Terrestrial System (UMTS), a new access technology namely Wideband Code Division Multiple Access (WCDMA) was developed. The access network in UMTS emulates a circuit switched connection for voice services and a packet switched connection for data services. Incoming data services in UMTS had to still rely upon the circuit switched core for paging. To overcome this shortcoming, pure IP based Evolved Packet System (EPS) was developed.

In EPS system, both voice services and data services are carried by the IP. A new access solution called Long Term Evolution (LTE) which is based on Orthogonal Frequency Division Multiple Access (OFDMA) is used to achieve high data rates. The LTE access network is simply a network of smart base stations (evolved Node B) without any centralized intelligent controller, generating a flat architecture. Distributing the intelligence amongst the base-stations in LTE reduced the time required for setting-up the connection and for handover.

5G, in turn, is result of evolution of existing standards coupled with the complementary new technologies. Some of these technologies will be discussed in subsequent paragraphs. It will supplement the 2G, 3G and 4G mobile networks currently deployed in our country. It is expected to add evolutionary and revolutionary services due to its faster speed, extremely low latency and higher bandwidth (capacity). Revolutionary services of 5G are well beyond prior generation networks.

DOWNLOAD SPEEDS

Generation	Technology	Maximum Download speed	Typical Value*
2G	GPRS, EDGE	0.1-0.3 Mbps4	<0.1 Mbps
3G	HSPA+5	21Mbps	8Mbps
4G	LTE	150Mbps	12-15 Mbps
5G	5G	1000-10,000Mbps	TBC

*Typical download speed is the one we experience on day-to-day basis. The actual Download speed depends on many factors like location, indoors/outdoors, the Distance to nearby tower and amount of traffic congestion on them.

Download time of some of the commonly used applications is indicated below:

Activity	4G Download Time	3G Download Time	2G Download Time
Accessing typical web page	0.5 Seconds	4 Seconds	3 Minutes
Sending an email w/o attachment	<0.1 Seconds	<0.1 Seconds	1 Second
Downloading High quality photograph	0.5 Seconds	4 Seconds	3 Minute

Downloading a music track (MP3)	3 Seconds	10 Seconds	7 Minute
Downloading an Application	8 Seconds	1 Minute	40 Minute

Download speeds needed for some of the commonly used streaming applications are:

Activity	Required Download Speed
Skype/WhatsApp call	0.1 Mbps
Skype video call	0.5 Mbps
Listening to online radio	0.2 Mbps
Watching YouTube videos (basic quality)	0.5 Mbps

LATENCY

Besides download speed, latency is another really important concept that affects the experience that one gets on his smart phone. It's also known as "lag" or 'Ping".

When your smart phone wants to download some content from internet, there is an initial delay before server on the other end starts to respond. Only after the server has responded it will be possible for download to commence. This initial delay is called latency. High latency connections can cause web page to load slowly and can also affect experience in applications that require real time connectivity, for example voice calling, video calling and gaming applications.

It is widely argued that benefits of 5G are more from having reduced latency and increased capacity rather than having faster download speeds. This is because download speeds available on 4G are fast enough for most uses [e.g., 5 Mbps is already more than enough for High Definition (HD) video]. However, despite faster download speeds not making a huge difference here, the reduction in latency from 5G technology will help overall response time. The reduced latency of 5G technology is particularly important in some of the newer embedded applications of mobile technology. For instance, a connected car travelling on express way at 110 kmph would travel almost 2 meters in the amount of time it takes for a 4G network to respond (latency being 50 ms: distance travelled in 50ms=110*1000*.05/60*60=2 meters. In case of 5G latency being 1ms this distance would be about 4 cm only. Thus, the lower latency of 5G connection will allow mobile technology to be used more safely in such applications.

Generation	Typical Latency
2G	500ms (0.5 seconds)
3G	100ms (0.1 Seconds)
4G	50ms (0.05 Seconds)
5G	1ms(0.001Seconds) * * this is target latency for 5G (theoretical.); other figures are based on real world usage.

Growth of subscriber base of 2G, 3G and 4G was largely 'demand-led' growth. Mobile telephony came to India when customer base was extremely low; total no. of exchange lines was merely 1.8 crore in 1997(Source TRAI). Hence, there was huge wait listed as well as latent demand and telephone subscriptions grew leaps and bounds with the availability of Mobile telephones on demand-a big change (of relief) from long waiting list era. However, growth in 5G is expected to be largely 'supply-led'. This is because for the first time in evolution of wireless networks from the days of 2G onwards, 5G will not be restricted to telecom sector/vertical alone. It will have its utility in multiple sectors affecting growth and efficiency of those sectors.

2G, 3G and 4G delivered services on personal phone platforms, whereas 5G will additionally also connect a very large number and variety of new devices including

- Machines (M2M communication),
- Sensors,
- Actuators,
- Vehicles (connected cars, Autonomous vehicles etc.),
- Robots,
- Drones, etc.

5G: Key Enablers

Spectrum and Network:

Spectrum

To achieve large bandwidth and high data rates new frequency band as below are used for 5G. High band/millimeter band included in 5G standards 24-39GHz (Giga Hertz) gives very high speed/bit rate but very short range. So, it's more like a public Wi-Fi than a traditional cellular network with lot of local, low power cell-sites rather than a few big ones.

Concerning 26 GHz band there has been an ongoing dispute between Indian Telecom industry and DOT (Department of Telecommunications, Government of India). This is regarding ISRO's (Indian Space Research Organization) demand to cut down transmission power of 5G base stations from 60 dbm to 37 dbm as it requires a small portion of 26 GHz band for satellite services without any interference from the 5G mobile network. Industry protested on the ground that it would increase deployment cost by 16 times making 5G services completely unviable. However, ITU (International Telecommunications Union) dismissed the proposal and upheld the view of industry at the WRC (World Radio Communications) 2019 conference held in Egypt. It has thus paved the way for telecom operators to commercially use 26 GHz band for ultra- fast wireless broad band services. It may not be out of place to mention here that India has a very large amount of 3250 MHz (Mega Hertz) of spectrum (Airwaves) in this premium band as opposed to merely 175 MHz in the 3.5 GHz band that DOT plans to auction.

- New frequency bands (3.5 GHz, 24 to 39GHz).

  (Mid Band 2.5/3.5Mhz, High Band 24-39 MHz).
- Use of unlicensed band for off-loading the traffic.

High frequencies are vital for providing high data rates in 5G, however propagation characteristics in these frequencies is hostile resulting in very short range. To combat the challenging propagation conditions at these frequencies, deployment of Advanced Antennae System (AAS) plays a major role. Following techniques alongside AAS are used to realize high speed in 5G networks.

Network

- Deployment of small cells (Network densification).
- AAS-MIMO (Multiple Input Multiple Output) & Beam forming.
- Cloud based RAN (Radio Access Network).

MIMO is the ability to transmit multiple data streams, using the same time and frequency resource where each data stream can be beam-formed.

Beam-forming is the ability to direct radio energy through the radio channel towards a specific receiver. Suitable adjustment in the phase and amplitude of the transmitted signal results in constructive addition of the corresponding signals at the UE (user equipment) receiver. This increases the received signal strength and thus the end user throughput.

Next Generation (NG) Core of 5G.

Some of the important Characteristics of 5G NG core are

- Edge computing-to support low latency applications
- Network Function Virtualization (NFV) & Software Defined Networks (SDN)
- Control and user plane separation
- Network slicing (Network as a service) to support application specific QOS (Quality of Service)
- Realtime Machine learning/Artificial Intelligence (AI).

5G has demanding service and network requirements prescribed by 3GPP (3rd Generation Partnership project- a standards organization that develops protocols for mobile telephony).

To meet these, a fundamental change to the core architecture is required. Simply upgrading the existing LTE (Long Term Evolution) core would not be able to support the varied requirement of all envisaged use cases.

With SDN and NFV supporting the underlying physical infrastructure, 5G comprehensively cloudifies access transport and core networks.

SDN is about the separation of the network control traffic (control plane) and the user specific traffic (data plane/user plane). A philosophy of centralization of configuration and control ,while ensuring simple data plane/user plane architecture, is thus followed with obvious advantage of reducing complexity and giving flexibility on the user side.

NFV is about, as the name suggests, virtualising network functions by implementing them in software able to run on standard hardware. As is known, cloud and virtualisation based platforms allow tremendous flexibility. Thus in 5G core architecture, SDN, NFV and cloudification allow many different functions to be built, configured, connected and deployed dynamically at the need based scale at any given time. It not only facilitates flexible use of resources and efficient network control but also brings the real power of 5G to the fore to make it multi - sectoral technology. Cloud adoption allows better support for diversified 5G services, and enables the key technologies of end-to-end network slicing ,on-demand deployment of service and component-based network functions. It also simplifies scaling and management of physical network infrastructure.

SERVICE BASED ARCHITECTURE AND INTERFACE

3GPP identifies two representation of 5G core architecture: point-to-point (P2P) based and service based (SBA). The P2P architecture has been used in 2G, 3G and 4G.

P2P architecture presents difficulties in making changes in a deployed system because of its large number of unique interfaces between functional elements. When a new element is introduced or existing one is upgraded, multiple adjacent functions need to be reconfigured.

On the other hand, the SBA decouples the end user service from the underlying network and platform infrastructure eliminating the necessity for interfaces between functional elements, thereby achieving both functional and service agility.

CONTROL PLANE AND USER PLANE SEPARATION

Independent scalability and decoupled technical evolution were enabled due to control and user plane separation. This also facilitated flexible deployments, such as at centralised and edge locations. This feature can also be applied to the EPC (Evolved Packet Core) in 4G as an upgrade. This upgrade enables the EPC to meet increasing traffic demands at lower cost-per-bit, and to serve low-latency applications hosted in edge locations. It, thus, also provides an important migration path from 4G to 5G.

NETWORK SLICING

This is another powerful feature of 5G NG Core, and supports new business domains. Network slicing permits business customers to avail connectivity and data processing customised to the specific business requirements in accordance with a service level agreement (SLA) agreed with the telecom service provider.

A host of network capabilities viz. data speed, quality of service, latency, reliability, security, services and tariffication can be customised and network sliced accordingly.

5G HIGH LEVEL FORUM (HLF)

Seeing cross sectorial impact potential of 5G, the government of India had set up a HLF in 2017 to evaluate and approve roadmaps and action plans to bring 5G in the country by 2020. HLF comprised members from academia, industry, and secretaries of DOT, Department of Science and Technology (DST) and Ministry of Electronics and Information Technology (MEITY). A corpus of INR 500 crores was set aside for Research and Development activities in this regard.

The HLF submitted report entitled "Making India 5G Ready" dated 23 August 2018 (https://dot.gov.in/sites/default/files/5G%20Steering%20Committee%20report%20v%2026.pdf) and pushed for 5G use cases and field trials. A steering committee chaired by Prof A J Paul Raj of Stanford University (Member HLF) created seven task forces including ones around Spectrum Policy, Regulatory Policy, Application and Use case labs (UCL) among others. HLF report recommended establishing application and use cases labs in India and developing "locally tailored solutions" (emphasis supplied). UCL Task force recommended that use case labs be set up in each economic vertical-with Agriculture, Health, Banking and Railways UCLs to start in first phase.

EFFORTS TOWARDS DEVELOPING INDIA SPECIFIC USE CASES:

5G Test beds and Use case development

Government of India launched a three year programme namely "Building an End to End 5G Test bed" to advance innovation and research in 5G(The Programme). It began in March, 2018 with a budget of INR 224 crores. The programme involves designing and fabricating multiple high-end components such as baseband processing units ,remote radio heads, Radio Frequency (RF) modules ,core network , interconnects and baseband algorithms and software.

The programme has been awarded to IIT Madras, IIT Hyderabad, IIT Delhi, IIT Kanpur, Centre of Excellence in Wireless Technology (CEWiT), Society for Applied Microwave Electronics Engineering and Research (SAMEER) and Indian Institute of Science (IISc), Bangalore.

The test bed, located partly in all these institutions, envisages close collaboration between the universities and start-ups and creates an ecosystem that closely resembles a real-world 5G deployment. The project is likely to enhance the national capability in telecom technology and manufacturing and create Intellectual Property (IP). The test bed is already collaborating with quite a few start-ups working on 5G. The Programme is said to be on track and Test bed(s) are likely to be ready by March 2021.

5G- Opens Up New Use Cases

As discussed before, 5G has three basic capabilities of providing high capacity, ultra-high data speeds and extremely low latency apart from many other technological features not available in earlier generations of mobile communication, making it suitable for use in many industry verticals. Hence, 5G opens up new use cases based on/centered around these capabilities and can be classified under following heads.

- Enhanced mobile broadband
- Massive IoT (Internet of Things)
- Critical Communications.

Enhanced Mobile broadband

It facilitates

- Pervasive high-speed video,
- Broadband access in crowded areas (e.g., Stadiums, concerts),
- Broadband access on high-speed trains, moving hotspots,
- Live TV at large scale and on-demand anything among others.

Massive IoT/M2M

It is interesting to see how M2M (Machine to Machine) communication and Internet of Things (IoT) have evolved.

- Pre-Internet; Voice calls, SMS.
- www-Internet of Contents like email, information, entertainment etc.
- Web2.0: Integration of IT Platforms and IT services gave birth to -Internet of Services like e Productivity, E Commerce etc.
- Addition of devices and Apps gave rise to Internet of People-Social Media like Skype, Face book etc.
- Internet of things which is ability to connect

sensors, tags, actuators etc. and Big data analytics gave rise to M2M and IoT.

- Machine-to-Machine (M2M) communications are automated applications which involve machines or devices communicating through a network without human intervention. They also can communicate interactively i.e. communicate, analyse and use collected information to drive further intelligent actions. This requirement creates a hyperdense wireless communication environment in a factory where large no. of assembly line machines, Automated Guided Vehicles (AGVs) ,tools etc. communicate almost simultaneously and in real time.5G is capable of meeting this requirement. It gives rise to Industry 4.0.
- M2M is the basis for automated information interchange between machines and a control centre for various industry verticals like Smart City, Smart Grid, Smart Water, Smart Transportation, Smart Health etc.
- M2M uses a device (such as a sensor or meter) to capture an event, which is relayed through a network (wireless, wired or hybrid) to an application, that translates the captured event into meaningful information.
- M2M can bring substantial and tangible social and economic benefits to consumers, businesses, citizens and governments.

M2M/IOT-WHAT CAN IT DO?

1. HOME: Security, Infotainment, Smoke Alarm, Energy Monitoring, Remote controlling Appliances.
2. TRANSPORT (Mobility): Traffic Routing, Telematics, Smart parking, Fleet management, Toll collection.
3. HEALTH: Patient care, Bio-wearables, Elderly monitoring, Remote diagnostics, Equipment monitoring.
4. BUILDINGS: Energy credits, Emergency Security, Smart Lighting.
5. CITIES: Waste management; Surveillance; Smart grid; Water management; Emergency services.
6. POWER: Flexible charging; Real time troubleshooting; Reliability; Cost savings.
7. ENVIRONMENT FRIENDLY.
8. AGRICULTURE: Smart irrigation; Real-time weather data; Remote monitoring of insect count; Monitoring of fertilizers waste.

Critical Communications

Some of the use cases in this category are

- Automated traffic control and autonomous cars.
- Immersive Augmented Reality (AR) &Virtual Reality (VR).
- Collaborative Robots. This has widespread use in smart manufacturing (Industry 4.0) among others.
- Remote control of heavy machinery.
- Remote surgery.
- Autonomous (Self driving) cars require high speed, low latency internet to make the vehicle much faster and smarter. With 5G cars will receive immediate updates from nearby sensors and IoT devices, which could make cars fully autonomous. 5G will improve the response time and better location awareness because of its lower latency and ability to off load computing tasks.
- 5G will provide real-time high-quality video required by Telemedicine.

Some of the key use cases are now discussed in a bit more detail in following paragraphs.

INDUSTRY 4.0 –A KEY USE CASE FOR 5G

A key use for 5G is to support Industry 4.0 connectivity requirements. We are currently passing through a significant transformation regarding the way products are produced including end-to-end supply chain. This is due to digitization of whole manufacturing and related processes. This transition is so compelling that it is being called Industry 4.0 to represent the "Fourth Industrial Revolution". The person who labeled these advances as a new revolution- The Fourth Industrial Revolution-is Klaus Shwab, founder and executive chairman of the World Economic Forum and author of a book entitled "The fourth Industrial Revolution".

Mechanization through water and steam power (18th century-1770s), Mass production and assembly lines using electricity (19th Century-1880s) are called First (Industry- 1.0) and Second Industrial revolution (Industry-2.0) respectively. Third Industrial Revolution (Industry-3.0) took place in the 20th Century, at around 1970, with the adoption of computers and automation i.e., the electronics and information technology (IT) enabled mass automation.

So, what is this Industry 4.0? It is connecting cyber-world with real (physical) world through CPS (Cyber Physical Systems). A CPS is an integration of systems with different natures whose main purpose is to control a physical process and, through feedback, adapt itself to new conditions in real time. Thus, these are created at the intersection of physical processes, networking and computation as indicated later in this paper while listing foundational technologies of Industry 4.0.

The essential components of CPS are interconnected objects which, through sensors, actuators and a network connection, generate and acquire data of various kinds. With the help of integrated sensors, CPS can determine their current operating status on their own within the environment in which they are located. Actuators, then carry out planned actions or to implement corrective decisions based on status so determined. Decisions are made by AI which evaluates information from its own internal sensors and information shared by other CPS. Communication is vital in CPS as they allow different objects to exchange information with each other and with humans at any time in any condition. Here, manufacturing systems go beyond simple connection, to communicating interactively; and while doing so, at every stage, analyzing the information contained in piece of communication, to drive further intelligent actions. For example, data will flow from customers via intelligent products to producers enabling quicker product development and novel services rendering. AGVs (Autonomous Guided Vehicles) on shop floor delivering parts/sub-assemblies to different machines, communicate interactively to take actions regarding supply/ non supply in real time. This needs high capacity, high speed, ultra- low latency communication system provided by 5G.

Industry 4.0 optimizes the computerization of Industry 3.0. When computers were introduced in Industry 3.0, it was disruptive, because of addition of an entirely new technology. Now and into the future as Industry 4.0 unfolds, computers are connected and communicate with each other to ultimately make decisions without human involvement. A combination of CPS, IOT and the internet of systems make Industry 4.0 possible and smart factory a reality.

Industry 4.0 represents an integration of following foundational technologies:

- Connectivity, Data and Computational power. (IOT, Sensors, Cloud Technology, Block Chain)
- Analytics and Intelligence.(Big Data Analytics, Artificial Intelligence AI and Machine learning ML)
- Human Machine Interaction (Intelligent Robots, collaborative Robots-Cobots, Chatbots, Augumented Reality and Virtual Reality AR/VR, Robotic Process Automation RPA)
- Advanced Engineering/Advanced manufacturing Technologies (3D Printing, Additive manufacturing, Nano Particles, Renewable Energy).

Investment in hyper-dense indoor networks in manufacturing facilities can massively improve productivity and enable innovation with concomitant socio-economic benefits. Fusion of virtual and real worlds based on Cyber-physical production systems (CPS) drives restructuring of value creation and supply chains. Communication is vital in cyber-physical systems, as they allow different objects to exchange information with each other and with humans, at any time and in any condition.

Hundreds of different Industry 4.0 applications can be present on the same site. Each of these require connectivity; with different requirements in terms of throughput, latency, reliability and number of end points. This requires a wireless network that covers the full site ,provides the highest level of reliability and ultra-low latency, and meets peak bandwidth requirement of all applications- all with different tailored “network slices” for different uses. Therefore Industry 4.0 on industrial sites requires appropriate 5G network connectivity.

DIGITAL TWINS

A ‘Digital Twin’ is a digital representation (Cyber replica) of a physical asset or system across its lifecycle using real time data to enable understanding ,learning ,reasoning and dynamically recalibrating for improved decision making and drive positive business outcome. A digital twin can also help in design phase of complex projects. Connectivity is one of the essential building blocks* of a Digital Twin, that feeds the sensor data to the digital models so that they can accurately replicate real world scenarios in a virtual environment.

5G enables creating Digital Twins which is an excellent example of the ability of CPS to create and combine the ‘physical’ and ‘digital’ aspects of products, systems, and processes. It involves creating a cyber replica of the physical site enabling digital operations on the digital site. Physical machines in the factory are fitted with large numbers of sensors that send status data on continuous basis to a virtual reproduction. Engineers can work on potential problems and possible solutions directly in this cyber replica.

5G-AS-A-SERVICE FOR INDUSTRY 4.0

5G technology can be provided as a service to increase implementation of Industry 4.0 reducing the capex requirement on the part of a particular industry. This will specially be very useful for SME sector with their limited cash flow and will help them reap benefits of Industry 4.0.

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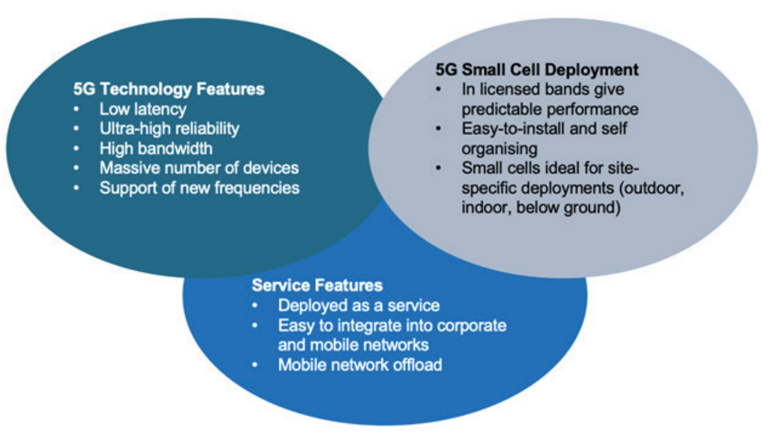
*other building blocks of digital twin are: Simulation(AI/ML,CAD,GIS etc),Sensors(IOT sensors for measuring physical quantities like temperature, pressure, humidity etc),Data Intelligence(Big Data Analytics, AI/ML etc) and Digital Twin Clients (AR, VR, Mobile and PC apps etc).



5G-as-a-Service Small Cells provide the solutions for these diverse requirements

5G AND SMART AGRICULTURE

Leveraging the potential of 5G for bringing efficiency and thereby increasing out-put in agricultural sector which still employs largest portion of Indian population hardly needs to be emphasised.

Smart Agriculture is the use of ICT (Information and Communication Technologies) to enhance, monitor, and improve agricultural operations and processes. Sensors are used to collect information such as soil moisture, presence or otherwise or level of nutrients (fertilization),weather etc. and transmit to a central hub providing farmers real time access to information and analysis on their land, crop etc.

This enables farmers to improve operational performance of their farming by analysing the data collected and acting upon it to increase productivity and also streamlining their agricultural operations/ processes. With 5G speed and bandwidth a large number of smart agriculture applications are set to emerge taking IoT in agriculture to new heights. 5G is expected to play an important role in India's aim of doubling the income of farmers by bringing efficiency in agricultural operations through water management, fertigation** ,fighting crop diseases, Aerial crop monitoring, seeding and spraying, livestock safety and maturity monitoring, crop communication etc.

5G IN MEDICAL AND HEALTH CARE- HEALTHCARE IS POISED TO BE SIGNIFICANTLY BENEFITED BY 5G

With the geographical size & large rural population living in far flung area of India, providing adequate health care to citizens has always been a challenge. Conventional means of providing medical facilities through brick and mortar hospitals and health care centres are never going to meet the demand/suffice in any time in near future. Pandemic COVID 19 has brought the problem of inadequate medical and health infrastructure to the fore, yet again. It has brought importance of Tele-medicine in focus. 5G will give boost to India's effort towards proliferation of tele-medicine.

Telemedicine involves remote patient monitoring and consultation necessitating video call and often transmitting images (X-Ray, Ultrasound, CT Scan etc) for diagnostic purpose .This puts extra strain on existing network which most of the time experiences congestion due to heavy customer traffic and less band-with capability. 5G technologies have the potential to help resolve these challenges.

Some of the ways in which 5G can support medical and health care are:

Transmission of Large Imaging Files

MRIs and other diagnostic imaging files are typically very large files(>35Mb for normal resolution, could be more for higher resolution, PET scanners generate extremely large files-up to 1 Gigabyte per patient per study) and often need to be sent to specialist doctor for proper diagnosis/review in shortest possible time in view of medical emergencies. When the network is slow (low bandwidth), the transmission can take a long time or not send it successfully. This means long wait for patient for getting treatment on one hand and doctor being able to see fewer patients in the same amount of time on other-not a desirable situation. With its high bandwidth capability of 1-10 Gigabits per second 5G effectively mitigates the situation.

Expanding Telemedicine

The telemedicine market is expected to grow at a compound annual growth rate of 16.5% from 2017 to 2023 according to a study conducted by Market Research Future. The reason for predicted increase is determined to be increase in demand in rural areas for healthcare as well as increased Government initiatives. Real-time high quality video supporting network is needed for telemedicine which often means wired network-usually optical fibre cable (OFC) network. Reach

**Fertigation is defined as the injection of fertilizers, soil amendments and other products typically needed by farmers into soil.

of OFC in our country is extremely limited currently, though initiatives are on to increase the same. 5G mobile networks can handle telemedicine applications resulting in considerable increase in the reach of the programme.

Use of AR, VR in Telemedicine

5G enables use of Augmented Reality/Virtual Reality in providing telemedicine, owing to its capability of high capacity and extremely low latency. This may enhance a doctor's ability to deliver innovative, less invasive treatments. Among 5G's many potential applications, most exciting seems to be the one involving it's role in simulating complex medical scenarios to enable alternative treatments for the critically ill.

Reliable, Real-time Remote Monitoring

Despite its benefits, usage of real-time remote monitoring technology in healthcare is currently limited by the data handling capacity of the network. Slow speed and low reliability of network prevents real-time data availability to doctor which is essentially needed by him/her to make quick healthcare decisions. With its lower latency and high capacity, 5G offers reliable real-time remote monitoring for more patients while healthcare providers can remain confident of receiving the data they need to provide expected care to their patients.

Artificial Intelligence (AI)

AI can be used in diagnosis and deciding most suitable treatment plan for a specific patient. Also AI can help predict likelihood of post-operative complication in a particular patient. The large amount of data needed for real time rapid learning for AI tools require ultra- high bandwidth network. Coupled with this doctors often need to access data from their mobile handsets.

5G enables health care organizations to use AI tools for providing best medical care possible from wherever they are!

5G WILL ACT AS CATALYST TO DIGITAL REVOLUTION IN INDIA

- It will advance the reach and utility of "DIGITAL INDIA" and allied missions.
- Put together the new use cases opened up by 5G can unleash new economic opportunities.

5G will enable India to leapfrog the traditional barriers to development. It has potential for being a transformational force if harnessed properly. However, reasonable spectrum pricing and Supportive regulatory policy will play a key role. This coupled with other efforts underway, as discussed before, will be essential for India being able to exploit full potential of 5G.

5G VISION FOR INDIA

"5G technology has the potential for ushering a major societal transformation in India by enabling a rapid expansion of the role of information technology across manufacturing, education, healthcare, agriculture, financial and social sectors. India must embrace this opportunity by deploying 5G networks early, efficiently, and pervasively, as well as emerge as a significant innovator and technology supplier at the global levels. Emphasis should be placed on 5G touching the lives of rural and weaker economic segments so as to make it a truly inclusive technology."

(Source: Making India 5G ready report of 5G High Level Forum of Govt. of India, 23 August 2018.)

Prof Rajni Hatti Kaul
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Author's Profile

Rajni Hatti Kaul is Professor in Biotechnology and Director of International Master Programme in Biotechnology at Lund University in Sweden. She got her PhD in Biochemistry from University of Bombay in 1984.

Prof Kaul's research is aimed at the development and use of biotechnology tools for a sustainable society. She has been leading interdisciplinary research projects involving academia-industry collaborations dealing with R&D on developing environment-friendly processes for production of chemical building blocks from renewable resources that could replace fossil based products. Other research deals with evaluating biological antimicrobial molecules for treatment of bacterial infections with an aim to reduce antibiotic resistance.

She was awarded Swedish Chemical Engineers Association award in 2010 for contribution in green chemistry. Since 2016, Prof Rajni Hatti Kaul is Director of a multidisciplinary research programme STEPS - Sustainable Plastics and Transition Pathways involving several research groups and stakeholders representing the plastic value chain (steps-mistra.se).

Prof Kaul has supervised more than 35 PhD graduates, many of them as main supervisor. Over more than two decades, she has been active in projects with several universities in Africa, Asia and South America, involving research training to staff and students. RHK has published more than 200 papers in international journals and edited 3 books. She is a co-founder of 3 spin-off companies since 2012.

Engineering a Sustainable Plastics System for the Future

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PLASTIC – A BLESSING AND A CURSE

Plastic – the lightweight, moldable, durable material - is so much a part of our lives now that we do not even notice its presence. Often referred to in a singular term, plastic comprises materials of many different compositions and properties. Our dependence on plastics is reflected in the dramatic increase in their production from nearly 2 million tons in 1950 to about 360 million tons in 2018 [1, 2]. Plastics are an important part of the modern global economy, being used in a vast variety of products and applications ranging from simple packaging materials, containers, furniture, construction materials to advanced lightweight engineering materials for automotive and aerospace industries, electronics and communications industries, several biomedical materials, etc. [3, 4]. Plastics have helped in saving resources and indeed our lives too, some examples being the increase in the shelf life of foods, saving energy, lowering emissions, insulation, maintaining safety and sterility of products, etc.

Although the first plastic like materials were made as early as in the 19th century from natural polymers like cellulose (e.g. Parkesine, celluloid, photographic films and viscose), rubber and protein, it was not until 1907 that the first synthetic plastic – bakelite – also called as the material of 1000 uses – was made [5,6]. Subsequently, several different polymers were invented – some accidently while the others using innovative chemistry for targeting the needs of the time. As a result, the twentieth century saw the development of a number of synthetic plastic materials with different chemistries and properties suited for myriad applications unparalleled by any other natural material. The main component of plastics is a polymer that is mixed with different additives to enhance certain properties and shelf life of the materials; these include plasticizers, stabilizers, antioxidants, flame-retardants, and pigments.

The plastics have however been in focus not because of the benefits we have gained through their use but for the health risks and environmental damage caused by their widespread use and uncontrolled disposal on land and in oceans [7, 8]. There has been concern over the years about the effect of persistent and toxic chemicals used as plastic additives on humans [8, 9]. Global generation of post-consumer plastic waste is estimated at present to be around 150 million tons per annum [10, 11]; only a small fraction is recycled, while a major part is incinerated for energy recovery (resulting in CO_2 emission) and a significant amount is dumped in landfills and discarded randomly in the natural habitats where it accumulates for long periods of time (hundreds of years) without getting completely degraded [12, 13]. Furthermore, 33% of plastics are used only once, and then thrown away with only 8% being recycled and converted to low-value products that (more often than not) cannot be recycled again [7]. This is particularly true for the single-use plastics that contribute to the increasing urban litter problem especially in developing countries due to inefficient or non-existent waste management.

Leakage of plastics in the oceans, estimated at 8 MT per year has led to a total plastic accumulation of 150 MT. The harmful effects of the plastic debris on the natural resources and the living organisms in its original form as well as in the form of microplastics (particles ranging from few µm-500 µm generated by weathering of plastics) and the released toxic additives is widely known [14, 15]. Over 51 trillion pieces of microplastics weighing over 250000 tons are estimated to be floating at sea [16], and it is frequently stated that by 2050 there will be more plastic than fish in the ocean.

Dumping or incinerating the plastics after a short useful lifetime and inefficient or total lack of recycling does not only have a negative environmental impact but also implies enormous loss of the material value to the economy. It is estimated that 95% of the value of plastic packaging material equivalent to $80-120 billion is lost to the economy annually after a very short first use cycle [7].

Yet another critical aspect of the environmental impact of plastics is indeed their production based on the finite fossil raw material and energy, which is equivalent to an average of around 6% of the total fossil feedstock and associated with considerable greenhouse gas emissions. This share of fossil use could increase as a consequence of decarbonisation of energy and mobility sectors, and the petrochemical industry hoping on increase in plastic demand to become profitable. Global carbon emission attributed to plastic production in 2015 was estimated to be around 1.8 Gt, corresponding to 3.8% of the total carbon emission during that year [17]. Combining this with the emissions from the post-disposal and recycling processes, yields a much higher total carbon emission during the entire life cycle of plastics [18]. If the plastic usage were to continue at the same rate, it could account for 20% of the total fossil oil consumption and the associated GHG emissions would rise to 15% of the global annual carbon budget by 2050 [7].

NEED FOR CHANGE

Will replacing plastics with other materials have a lower environmental impact? Several studies have indicated otherwise – suggesting that substituting plastics with materials such as paper, glass, metal, cotton, etc. would lead to a large increase in the consumption of materials, energy, water and also the CO_2 emission. So how can we continue to reap the benefits of plastic materials without burdening the planet with it? For that to happen we need not only to improve our consumption patterns and attitudes, but also rethink plastic production, use and after-use so that the material instead of going as waste, reenters the economy as a valuable commodity. This implies an integrated approach of deploying upstream and downstream solutions for the plastics problem, i.e. decoupling production from fossil feedstock, design of plastics without inclusion of toxic additives and to possess features for recycling, and developing efficient plastic collection, tracing, sorting and recycling systems [19] **(Fig. 1)**. This will lead not only to reduction of waste and carbon footprint but also capture the economic value as well as conserve natural resources [7]. As determined by Ellen Macarthur

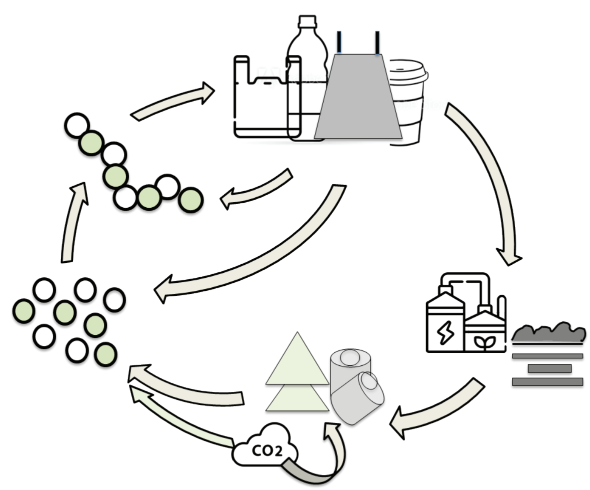

Fig. 1 : Schematic overview of a circular plastics economy, which involves shifting production from fossil to renewable feedstock including biomass, CO_2, etc., design of plastics to possess features for mechanical or chemical recycling, and alternatively recycling the carbon by biodegradation in a controlled environment.

Foundation [20], a comprehensive circular economy approach could reduce the volume of plastic leaking into the oceans by >80% and generate savings of $200 billion yearly, and also reduce GHG emissions by 25%.

PLASTIC DESIGN FOR RECYCLING AND REUSE

So far incentives for recycling have been few due to low cost of plastic and dumping the plastic waste on developing countries [21]. But with increasing societal awareness of the plastic pollution and the economic losses, and also the number of countries refusing to accept the contaminated plastic waste, there is increasing demand on making recycling and reuse of plastics mainstream and even profitable. According to a Mckinsey report in 2018, "plastics reuse and recycling could generate profit-pool growth of as much as $60 billion for the petrochemicals and plastics sector" [22]. The European Strategy for Plastics in a Circular Economy has put emphasis on improved design and production of plastics and plastic products to facilitate reuse, repair and recycling [23].

The most common and economical method for recycling plastics used currently is that of mechanical recycling [11]. Only a limited variety of plastics are recycled by this means, which include low density polyethylene (LDPE), high density polyethylene (HDPE), polypropylene (PP) and polyethylene terephthalate (PET). Often the recycled product obtained is of lower value and is downcycled e.g. by mixing with other plastics to make a product of lower quality. Recycling of PET bottles is the only example of closed-loop recycling, wherein the recycled stream is used again for making bottles but needs to be mixed with virgin polymer since the polymer chains lose their molecular mass when exposed to the harsh process conditions. Majority of the plastics cannot be mechanically recycled because they may undergo thermal-mechanical degradation, the polymers in the mixed plastic waste may have differing thermal properties or the plastic additives may complicate the recycling process [24].

For the mechanical recycling to become applicable to a wider range of plastics, there is thus a need for designing high performance polymers with enhanced thermal-mechanical properties to avoid undue material loss. Glass transition temperature (T_g) of amorphous polymers is recognized as one of the most important characteristics that influences their thermal, mechanical and rheological properties. The degradation of PET during mechanical recycling is attributed to its relatively low T_g value of 74 ^{O}C. Hence, an effective strategy for improving the performance and recyclability of polymers, and even their optical transparency is to improve the T_g, which is achieved by introduction of rigid ring structures like aromatic and cycloaliphatic molecules that increases the rigidity and conformational stability of the polymer backbone [25]. Such an approach has been applied for making PET co-polyesters with higher T_g, some commercial products being TritanTM (Eastman) and AkestraTM (Perstorp) [24, 26].

Yet another form of recycling that shows promise is chemical recycling where the polymer is totally degraded into its constituents, which are then used to rebuild the original polymer or transformed into an alternative valuable product or a petrochemical feedstock [10]. The chemical recycling that is currently attracting increasing industrial attention is pyrolysis or thermochemical liquefaction (also called as feedstock recycling) at about 500 ^{O}C under 1-2 atm in the absence of oxygen, to a crude oil like material, a familiar feedstock for the petrochemical industry. This recycling process can be applied to mixed plastic wastes, multilayer packaging, composites, etc. that are currently incinerated or landfilled, and are difficult to depolymerize. The challenge with the mixed streams is the varying product spectra obtained that requires upgrading to produce the monomers for making virgin grade resins. The economic viability of this process depends on the availability of large volumes of the plastic waste feedstock.

An alternative to pyrolysis would be to subject the polymer to milder conditions enabling selective depolymerization into oligomer or preferably monomer components. The selectivity would potentially enable separation of polymers from blends and mixed wastes. Depending on the bonds linking the polymer chains, degradation may be stimulated using different agents such as chemicals, enzymes, temperature or light. One of the areas of great interest for chemical recycling is the separation of polyester-cotton blends in textile wastes [27]. Here, the requirements for the polymer design are to maintain the desired material properties during its useful lifetime and allow efficient depolymerization when needed. In a highly novel approach, it may also be possible to exploit the favorable thermodynamics of polymerization and depolymerization below and above the ceiling temperature Tc of a polymer for recycling [28]. Here, the challenge would be to design the polymers such that the processes of polymerization and depolymerization can occur within a reasonable temperature span for optimal use and recycling.

Rational design is also highly applicable for biodegradable polymers and the polymers that are difficult to recover after their application [26]. This is to ensure their complete biodegradation within a certain time period under defined environmental conditions while they retain the desired material properties when in use. Even for these polymers the right mix of the building blocks and chemical bonds, providing suitable durability and access of the microbial enzymes for degradation. Introduction of functional groups whose degradation can be triggered by another mechanism could provide an attractive alternative.

TRANSITION FROM FOSSIL TO RENEWABLE FEEDSTOCK

A shift in the raw material base to renewable resources is expected to be an important solution to conserving the fossil resources and in reducing the carbon footprint. Production of plastics from plant biomass is already a reality, although their growth has been slow due to a strong competition from the already established low cost fossil based plastics. The total production volume of bio-based building blocks and polymers was estimated to reach 7.5 MT in 2018, with the projection of growth until 2023 at a CAGR of about 4% [29]. Although making bio-based plastics is not a novel concept, In contrast to the materials made during the 19th century, the present day plastics have high demands to meet the standards of the material properties and the low cost set by the petrochemical industry, and over and above that also satisfy the societal demands for non-toxic and recyclable products.

The initial development of the bio-based plastics touted biodegradability of the products as the selling feature in contrast to the fossil based plastics, as the products would potentially get degraded by the micro organisms in the environment and hence provides a solution to the plastic waste problem. The biodegradable plastics include starch blends, poly (lactic acid) (PLA), poly (hydroxyalkanoates) (PHAs) and poly (butylene succinate) (PBS) [26]. Although the production and use of these plastics is increasing mostly in packaging but also in some specific applications, several of them have posed challenges in terms of being not fully compatible with the processing and recycling systems owing to their relatively poor thermal, mechanical and rheological properties and hence requiring copolymerization or blending with other polymers and additives. Moreover, not all the polymers are readily biodegradable, and the degradation rate and products formed depend on the environmental conditions; e.g. PLA is non-degradable in sea water [30].

On the other hand, the bio-based plastics made by replacing partly or wholly the components of the available fossil based plastics with "drop-in" molecules of bio-based origin, e.g. ethylene, ethylene glycol, 1, 3-propanediol, etc., e.g. bio-PE, bio-PET and bio-poly (trimethylene terephthalate) (bio-PTT), are readily accepted by the market, as they allow the use of existing infrastructure and the products familiar to the consumer. But they present the same challenges of limited recyclability as their fossil based counterparts. The content of the renewable carbon in the bio-based plastics thus varies between 20-100%. There is a clear preference for recyclable plastics to enhance material value recovery, but the biodegradable plastics are interesting for applications where the recycling option is problematic e.g. in agriculture or cosmetics, and where it provides benefit, e.g. in collection of food waste.

Research during the past decades has further shown that high diversity of novel structures can be made available from biomass that can confer superior properties on the polymers. For example, poly (ethylene furanoate) (PEF), the polymer currently undergoing development as a potential substitute for PET, uses as a monomer 2,5-furan dicarboxylic acid (FDCA), an oxidation product of sugar based 5-hydroxymethyl furfural (HMF). PEF has superior thermal (T_g of 86 ^{O}C) and barrier properties (>6 times for O_2, 2 times for CO_2 and water) than PET, making it ideal for packaging applications [31].

Life cycle assessments have shown the production and use of bio-based plastics to be generally advantageous in terms of saving fossil resources and reducing greenhouse gas emissions [32, 33]. However, since most of the commercial products are based on primary agricultural feedstock such as starch and sugar, the above advantages may be compensated by the environmental impact of the production of the agricultural raw material in terms of acidification of soil and eutrophication [32, 34, 35]. Moreover, the aspect of land use and competition with food availability cannot be forgotten when more and more plastics and other products become bio-based in the emerging bioeconomy. For improving the environmental advantage of the bio-based plastics, integrated production in a biorefinery needs to be considered by making use of by-products and waste streams as feedstock, hence optimizing the use of arable land and making production cost-effective [32, 36, 37].

The biomass residues are primarily lignocellulosic and constitute potentially an enormous resource of sugars and aromatic compounds in the form of polysaccharides (predominantly cellulose but also hemicelluloses and pectin) and lignin. Processing of this recalcitrant material is energy-intensive and poses separation challenges. Hence immense R&D efforts are ongoing for developing technologies for valorizing residues arising from agriculture or forestry, and even organic industrial wastes as raw material, and these are likely to continue in the future. At the same time, developing technologies for using industrial waste gases such as syngas, CO_2 and CH_4 as the future raw materials for chemicals and materials, is gaining momentum [38-40]. This would potentially provide added benefits of converting the greenhouse gases to valuable products and saving both the virgin biomass and fossil feedstock.

It is thus evident that in order to make truly superior and safe bio-based plastics [41], besides the product design there is a need to strengthen the technology base for resource-efficient, environmentally benign and cost-effective transformation of varied renewable feedstock based on biomass of different origins as well as industrial wastes to the carbon-neutral and non-toxic building blocks and additives.

Industrial biotechnology and engineering biology – paving the way for a circular plastics system

Irrespective of the bio-based plastics being biodegradable or durable, industrial biotechnology has served as a key enabling technology for their production from renewable feedstock. The technology relies on the use of microorganisms and their enzymes for catalyzing the transformation of the renewable carbon to target products [42] **(Fig. 2)**. The vast diversity of microorganisms in nature is an invaluable source of innumerable metabolic pathways and enzymes for utilizing the available carbon (inorganic or organic) and obtaining the products of interest. Microorganisms and their enzymes are indeed key tools for different stages of the plastic cycle starting from depolymerization of recalcitrant complex biomass to its simpler components, transformation of organic or inorganic carbon to building blocks or polymers, and even degradation of the polymers to enable recycling. Moreover, biotechnology processes are characterized by mild conditions, nontoxic residues and low emissions, hence fulfilling most of the green chemistry principles [42].

Some familiar examples of industrial biotechnology making impact in the production of bio-based plastics are the microbial production of lactic acid, succinic acid and ethanol, from sugars by different organisms, which are used for the production of PLA, PBS and PE, respectively [26,42]. Several bacteria grown on different carbon sources accumulate the bio-polyester PHA as an energy reserve. Different classes of microbes have the metabolic capacity to use CO_2 as carbon source and reduce the gas to organic compounds, while others oxidize CH_4 [38]. Following the discovery of the plastic degrading microbe Ideonella sakaiensis [43], there is now growing enthusiasm among researchers for exploiting the potential of the biological catalysts for recycling of plastics [44]. For harnessing the industrial potential, engineering of the nature´s catalysts to make them more robust, selective and productive is often essential in order to develop cost-effective, clean processes **(Fig. 2)**.

Engineering biology has its roots in the revolutionary inventions in genetic technologies that have taken place after the discovery of DNA being the carrier of genetic information. The discovery of PCR (polymerase chain reaction) for multiplying DNA molecules and recombinant DNA technology enabling transfer of genes from one organism to another where the products coded by the genetic information i.e. proteins could be produced formed the basis of biotechnology industry. Subsequently, advent of rapid DNA sequencing technologies, triggered by the international collaborative efforts for mapping the human genome, has greatly accelerated the genome sequencing of innumerable organisms, and the knowledge of their metabolic capabilities, while bioinformatics became an invaluable computational tool for storing and comparing large amounts of data made available. Artificial gene synthesis was yet another milestone, which meant basically that customized DNA molecules carrying a desired chemical message can be obtained and introduced in a microorganism of interest for expression into an active protein.

In the 1990s, a new technique of metabolic engineering emerged that involves analysis of metabolic pathways in an organism and the inherent constraints in the production of desired compounds, and uses genetic engineering to relieve these constraints. The ultimate goal is to develop microbial factories that can be used at an industrial scale for manufacturing the

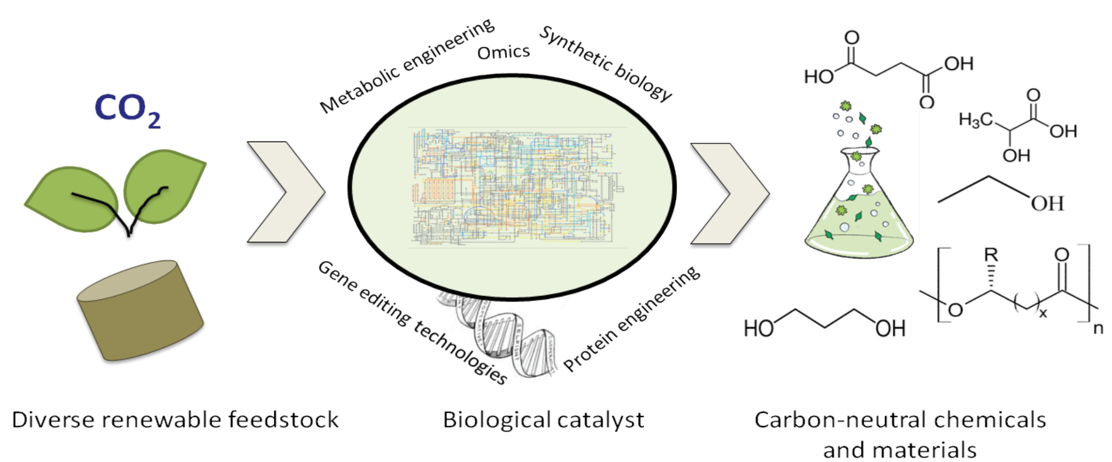

Fig. 2 : An overview of industrial biotechnology as a key technology area for the production of building blocks and polymers from renewable feedstock. The technology makes use of biological catalysts – microorganisms and enzymes – as process tools, which are engineered for industrial applications using several powerful modern technologies

products of interest. Metabolic engineering is aided by the knowledge gained from several omics technologies (genomics, proteomics, metabolomics, etc.) on regulation at the gene, protein and metabolic level and understanding interactions between the components that would influence the physiology of cells and also for determining the potential and design as cell factories [45]. It continues to evolve in efficiency and scale, being supported by breakthroughs in synthetic biology that merges a broad range of methodologies including mathematical modeling, computational simulations, machine learning, the artificial intelligence, robotics, etc. for obtaining quantitative information for the creation of models that can predict the behaviour of a biological system [46]. Invention of different gene editing technologies like Biobricks, CRISPR, etc. has been vital for development of the above areas. Even the enzyme molecules have been subjected to engineering to improve/modify their activity, stability and even selectivity. The so-called protein engineering is based on technologies for creating mutations either at specific sites on the enzyme molecules based on computational modeling, or randomly, or even fusing genes encoding different enzymes into one molecule. An interesting example of protein engineering is to enhance the activity of the microbial enzymes capable of catalyzing degradation of plastics, which in nature would take hundreds of years [47, 48]. All these powerful tools increase our capabilities of creating new organisms and enzymes for even catalyzing reactions not known to occur in nature, and will lead to a paradigm shift in manufacturing.

INCREASED DIGITIZATION OF MANUFACTURE, TRACING AND SORTING

In view of the different plastic types and vastly different applications, tracing collection and sorting present critical challenges for establishing an effective circular plastics system with minimal plastic leakage. In fact, we are already in an age where digitization is resulting in possibilities of identifying, tracking and data-managing every physical object including plastics throughout its lifecycle [49]. Rapid progress in digitization and automation of industrial equipment has set the stage for improving the productivity of plastic production, and also collection and sorting of the post-consumer plastic. There is a great demand for equipment that enables direct online information of the performance of machines, greater connectivity between multiple machines, process control technology and smart alerts to make up for any errors and lead to overall process optimization. Additive printing is becoming a mainstream technology for prototyping and customization of consumer products, and shows promise for production of plastic components up to a certain scale, and increasing the speed of production by several folds while reducing waste.

Segregation of plastics using different types of AI supported sensors is being developed. Sensors based on several different principles are known that confer very high accuracy of sorting and increase the quality of material output [50]. A few examples are the optical sensors that differentiate plastics based on color, shape and texture, while near infrared laser diodes recognize the characteristic resonant frequencies of the plastics. The use of AI minimizes uncertainties and enables smart and efficient sorting by training the system for accurate recognition and separation, resulting in increasing productivity and even lowering the health risk for the workers.

As a complement to the above advances, blockchain solutions for enabling circular supply chain are being attempted [50]. The technology is based on a digital marker that enables the secured sharing and validating of data about supply, demand, specifications, etc. between plastic waste segregators, recyclers and recycled feedstock buyers with an aim to improve sorting, tracing and monitoring of plastics throughout the value chain. Such advancements will potentially result in increased transparency, resource efficiency and life cycle of plastics, waste reduction, and a profitable model for circular economy of plastic waste.

CONCLUSION

Our planet has reached a tipping point; we need about 1.6 planets to provide the resources for our consumption and absorb our waste, and by the mid 2030s we will need 2 planets [51]. Hence, contrary to the current practice of take, make and dispose, we cannot afford to have the material flows within an economy as a one-way road. Plastics are valuable components of our economy and to create a circular plastic economy requires innovative and scalable engineering approaches and business models that should be supported by favourable policies and legislations. This paper summarizes various possibilities for engineering of plastic materials, plastic manufacture and plastic handling systems with a goal of increasing sustainability and resource efficiency, and reducing emissions and waste. In contrast to the industrial revolution brought about by exploitation of fossil coal and oil accumulated over millions of years from the biological materials and contributing to the greenhouse effect and climate change we face today, the coming years will see increased importance of engineering biology with clear goals of sustainability.

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The Rise of Algorithmic Decision Making: Ethics and Beyond

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OUTLINE

In this article we outline the ethical concerns that arise due to large-scale use of algorithmic decision making. We shall review the different forms of discrimination such as disparate treatment, disparate impact and disparate mistreatment. We shall next discuss the notions of algorithmic fairness and machine learning algorithms developed to formally encode these notions. In the next segment, we shall introduce the concept of platform governance where we shall discuss the ethical issues that are related to platform companies. In particular, we shall talk about hate speech analysis, fake news detection and algorithmic auditing of search, recommendation and ad delivery on different platforms. As a follow up we shall discuss the moral dilemmas that a machine can face while distributing harm where such harm is inevitable, e.g., crashing of an autonomous vehicle. In the final section, we shall briefly outline some of the issues specifically pertaining to India.

INTRODUCTION

With the worldwide internet penetration reaching 4.57 billion[1] the volume of data that is generated every day has reached 2.5 quintillion bytes[2] and this is only going to grow in the coming years. The computing paradigm is therefore increasingly becoming data-driven. While this has resulted in many benefits like online banking, e-commerce, social media platforms etc. there are also some obvious hind sides. One of the biggest challenges is the uprise of data-driven decision making, i.e., algorithms taking decisions in lieu of humans by churning past data. A fantastic exposition of this problem is made in the book Weapons of Math Destruction (O'Neil 2016) which outlines how big data increases inequality and threatens democracy. Example scenarios include video analysis of job candidates, automated screening of the resume in job applications, automated credit scoring of individuals to decide the disbursal of loans to them or automated criminality scoring and predicting chances of recidivism[3]. The moment algorithms are used to make decisions for the above tasks based on past data, there is potential risk of these decisions being biased. The source of such bias could be potentially rooted in the race, the gender, the age, the geography and other such factors which are cumulatively called protected or sensitive attributes. As soon as such protected attributes come in context there arises questions of algorithmic bias and fairness, accountability/transparency/explainability, ethics and moral responsibility. This has led to the emergence of a new and active area of research called data justice

1. https://www.statista.com/statistics/617136/digital-population-worldwide/
2 https://www.socialmediatoday.com/news/how-much-data-is-generated-every-minute-infographic-1/525692/#:~:text=%22Over%202.5%20quintillion%20bytes%20of,for%20every%20person%20on%20earth.%22
3. https://www.pewresearch.org/internet/2018/11/16/attitudes-toward-algorithmic-decision-making/

(Gorwa 2019) where the objective is to shift the focus from individual harm caused by data driven systems to the application of holistic principles of social justice.

Today's technological advances are often deemed to be disruptive as they tend to provoke disruptions in the legal and regulatory orders. The cyberspace is pretty much 'open'. There is no common and globally agreed set of laws or even ethical principles that can guide the proper functioning of this open space. There is no accessible judiciary such as a global cyber court, a government, a police force or a parliament that can work for the rights and entitlements of the users belonging to this space. For instance, there is an extensive volume of hate speech against target communities constituted from race, gender, age, sexual orientation, physical disability etc. is being generated across various social media platforms and are promoted in the guise of freedom of speech. A closely related issue is the spread of fake and false information that have become so powerful that they can even change the outcomes of a national election or cause riots. The irony is that even the most reputed media houses sometimes feature such behaviour leading to what is known as media bias (Mullainathan and Shleifer 2002). The imbalance in coverage of news, replacement of facts by opinions that would suit the ideology of the readers have given birth to what is known as the post-truth era.

Finally, most of the algorithmic decision making systems are trained to distribute benefits across individuals or groups. It is not clear how such algorithms should behave if they are faced to distribute harm. For instance, if autonomous vehicles go out of control while on road, the algorithm has to decide whether to save the passengers or the pedestrians on the road. It is far from obvious as to how algorithms would deal with such moral dilemmas (Maxmen 2018) in future.

In this article we shall discuss the above issues in more detail. We shall begin with algorithmic fairness and the initiatives around development of fair machine learning algorithms. We shall also discuss ideas of distributive justice. In the second part of the article we shall discuss the emerging issue of platform governance that encompasses issues like fake news and bias in media, hate speech and algorithmic auditing. Next we would touch upon the newly emerging concept of moral machines. Finally we shall present a brief synopsis of the state of affairs in India.

DISCRIMINATION OF DIFFERENT FORMS

Data mining enthusiasts have over the years tried to promote algorithmic decision-making as an alternative to eliminate the human biases. However, the catch here is that an algorithm can be only as good as the data it works on. Most often data is imperfect and may reflect the biases that already exist in the society. In fact, many surprising regularities extracted from the data might be reminiscent of the pre-existing patterns of exclusion and inequality that exist in the society. This issue is becoming increasingly important and in May 2014 the White House released a detailed report Big Data: Seizing Opportunities, Preserving Values (aka Podesta Report) (Barocas and Selbst 2015), which outlined the discriminatory potentials of big data. The report discussed how big data analytics can be of potential threat to civil rights protection through biased use of personal information in deciding access to employment, education, housing, credit health and the marketplace in general.

In order to understand the notion of discrimination there is a need to first have some quantitative definitions in place. The following three forms of discrimination could be thought of as the foundations:

Disparate Treatment: The decision outcome of the algorithm that a user receives changes with the change in the sensitive/protected attribute information (e.g., race, gender, age) of the user (Barocas and Selbst 2015). An example could be when an organization singles out an individual from a certain protected group and somehow treats them differently. For instance, in an interview process if women are intentionally singled out to perform a particular skill test then this would result in disparate treatment.

Disparate Impact: The decision outcome of the algorithm disproportionately benefits or hurts the interests of users of a certain protected class (Barocas and Selbst 2015). An example of this is when a protected group is usually negatively impacted even when the policies of the organization are apparently neutral. In other words, what matter is the outcome and not the intent. Written test for an interview is a neutral policy, however if a protected class members always get eliminated in the outcome of the written test then this amounts to disparate impact.

Disparate Mistreatment: An algorithmic decision-making process is said to suffer from disparate mistreatment if the misclassification rates of the algorithm differ based on the protected/ sensitive attribute (Zafar et al. 2017). One of the classic examples of this form of discrimination based on race has been brought in effect by the Correctional Offender Management Profiling for Alternative Sanctions, or the COMPAS tool[4]. This is a risk assessment tool developed by Tim Brennan and Dave Wells that assigns a recidivism score to a defendant based on the answers given by them to a set of 137 questions (aka COMPAS questionnaire) every time before they are sentenced. Sometimes, the data might also be pulled directly from the past criminal records of the defendant. In 2016, ProPublica did a detailed study[5] and showed that there exists significant racial disparities in the way the algorithm forecasts whether a person will reoffend. They found,

- The formula was very likely to incorrectly flag the black defendants as future criminals. They were misclassified at almost twice the rate as the white defendants.

- Further, the white defendants were mislabeled as low risk much more often than black defendants.

4. https://en.wikipedia.org/wiki/COMPAS_(software)

5. https://www.propublica.org/article/machine-bias-risk-assessments-in-criminal-sentencing

A real case of this misclassification is the following. In 2014, Brisha Borden was accused of burglary and petty theft amounting to $80. The previous summer Vernon Prater was arrested for shoplifting worth $83.35. Vernon Prater, a more seasoned criminal, had already been convicted of armed robbery. However, the computer algorithm produced a COMPAS score for Borden (recidivism score = 8), who is a black, way higher than Prater (recidivism score = 3), a white. In reality, in the next two years time Borden never reoffended while Prater is serving an eight years sentence for breaking into a warehouse and robbing electronic goods worth millions of dollars.

ALGORITHMIC FAIRNESS

We shall first discuss the notions of fairness and hen point different ways to ensure fairness in real systems.

Formalising Notions of Fairness

Let us consider for simplicity and without any loss of generalizability that the machine-learning task at hand is binary classification. In this type of task the goal is to learn a mapping $f(x)$ between a feature vector $x \in Rd$ (typically representing a user) and class labels $y \in \{-1, 1\}$. The mapping is learnt by computing a decision boundary usually denoted by θ^* that minimizes some form of a loss, say $L(\theta)$. In other words, $\theta^* = \mathrm{argmin}_\theta L(\theta)$ which is calculated using a training dataset $D = \{(x_i, y_i)\}, i = 1 \ldots N$. Now in the testing phase, for an unseen feature vector x, the classifier makes a prediction of the class label $y\ \hat{y} = f_\theta^*(x) = 1$ if $d_\theta \hat{y}(x) \geq 0$ and $y\ \hat{y} = -1$ otherwise. Here $d_\theta \hat{y}(x)$ is the signed distance from the vector x to the decision boundary. Let us further assume that the sensitive attribute of the user is denoted by z and that z is binary ($z \in \{0, 1\}$). Given the above formulation, we can now mathematically define the avoidance of the above discriminations as follows.

Avoiding disparate treatment: A binary classifier is said to be free from disparate treatment if $P(\hat{y}|x, z) = P(\hat{y}|x)$. In other words, the probability that the classifier outputs a certain value of $y\ \hat{y}$ is agnostic of the sensitive attribute z.

Avoiding disparate impact: A binary classifier is said to be free from disparate impact if $P(\hat{y} = 1|z = 0) = P(\hat{y} = 1|z = 1)$, i.e., the true positive rate is agnostic to the sensitive attribute z.

Avoiding disparate mistreatment: A binary classifier is said to be free from disparate impact if $P(\hat{y} \neq y|z = 0) = P(\hat{y} \neq y|z = 1)$. The most important among these are the false positive rate (FPR): $P(\hat{y} \neq y|z = 0, y = -1) = P(\hat{y} \neq y|z = 1, y = -1)$ and the false negative rate (FNR): $P(\hat{y} \neq y|z = 0, y = 1) = P(\hat{y} \neq y|z = 1, y = 1)$.

Fair Machine Learning Algorithms

Fairness through classifier constraints: As an example case we point out here the design of a classifier that mitigates the problem of disparate mistreatment (Zafar et al. 2017). Recall that the classifier learns a decision boundary by minimizing a loss function L(θ). One of the most important properties of such a function is that it has to be convex which ensures that the global optimum can be computed efficiently. One way to mitigate the effect of disparate treatment could be to incorporate the fairness criteria as a constraint as follows:

minimize L(θ)

subject to $P(\hat{y} \neq y|z = 0) - P(\hat{y} \neq y|z = 1) \leq \varepsilon$, P(=y $\hat{y} \neq y|z = 0) - P(\hat{y} \neq y|z = 1) \geq -\varepsilon$

where $\varepsilon \in R^+$ and smaller the value of ε,fairer is the decision boundary.

However, one of the biggest obstacles to solve this equation is that it no longer remains convex. However, with a little mathematical trick and suitable approximations, the above expression can be converted into a Disciplined Convex-Concave Program (DCCP) and then solved efficiently. The results on the ProPublica dataset shows that the algorithm is able to balance the false positive rate as well as the false negative rate for the classes (black and white) compared to the original algorithm without the fairness constraints.

Fairness through Convex Optimization: Recently, Google has introduced fairness goals in their TensorFlow Constrained Optimization (TFCO) library[6]. Let us consider a simple task of learning a classifier that predicts if a person should be given a loan or not based on historical data of whether the person was able to repay his/her earlier loans successfully. In order to set up the TFCO library one could choose an objective function that enforces the model to favor granting loans to those who have a higher chance of paying them back. At the same time suitable fairness constraints could be imposed on the model to prevent it from unfairly denying the grant of loans to individuals of a protected class. The library is so designed that the fairness criteria can be either added as a constraint for the optimization function or blended into the function itself.

PLATFORM GOVERNANCE

Platform governance (Gorwa 2019) refers to the layers of governance relationships that determine the interactions among the key stakeholders of modern day platform society, which includes the platform companies (e.g., Facebook, Twitter, WhatsApp, Amazon etc.), users, advertising agencies, governments and policy makers.

The need for Governance

With the rise of platform companies there is a surge in online activities across the world. In many cases such online activities have even been seen to have offline consequences. While a lot of virtues of such platform companies have been cited, there are equally many vices. Some of the issues that call for immediate attention are the rise and spread of hate speech and fake news in online social media platforms like Facebook, Twitter, WhatsApp etc. as well as the rising discrimination based on race, age, gender in ad delivery platforms (e.g, Facebook) and product search/recommendation in e-commerce platforms (e.g, Amazon). In the following we shall discuss the computational techniques that have become popular to study these items on platform companies and the governance measures taken thereof.

6. https://github.com/google-research/tensorflow_constrained_optimization

Hate Speech

Hate speech[7] is defined as any online post that 'promotes violence against other people on the basis of race, ethnicity, national origin, sexual orientation, gender, gender identity, religious affiliation, age, disability, or serious disease.' Even though platform companies and governments are trying to curb hate speech it seems to be constantly plaguing the online society sometimes translating to extremely unfortunate offline events. For instance, Facebook has been held responsible by the UN investigators, as playing a key role in the Rohingya genocide by allowing the free flow of hate speech on the platform[8]. In similar lines, Facebook has also been held responsible for igniting the anti-Muslim mob violence that left three people dead[9]. Very recently, Verizon has pulled off advertising on Facebook because of the inaction of the platform to contain hate speech[10]. The academic community has come forward to understand how hate speech spreads over different social media platforms and how the effect of such speech can be contained. One of the most important research problems in this domain is automatic detection of hate speech. The problem is hard because the semantics of hate speech is strongly tied to the demographic properties of the online users. For instance, in India 'beef-eating' can be a context for hate speech but not 'holocaust denial'. However, in the Western countries this would be just the opposite. Further, hate speech might not always indicate offensive words, i.e., they can be adversarial in nature. A nice example is 'six million was not enough'. It is very difficult for an algorithm to identify that this post is in the context of the number of deaths in the holocaust. Further, a post can be in multiple languages and in multiple modes (e.g., video, audio, image and text) which complicates the automation steps even more. Starting from feature based machine-learning approaches, researchers have applied all forms of modern deep learning machineries to detect hate speech. A recent interest of the academic community is to not only have the machine detect hate speech but also explain why it classified a post as hate speech. Another direction in hate speech is the analysis of the spread of hatred in social media. Recent study (Mathew et al. 2019a) has shown that in many social media platforms that promote freedom of speech (e.g., Gab.com)[11], help the growth of hate speech in the community by allowing it to spread further and deeper into the network. A followup work (Mathew et al. 2019b) has shown that hateful users quickly gain strategic positions in such a social network as compared to benevolent users and the entire social community gets aligned to the language spoken by hate speakers. The last stream of works in this area is how the spread of such hate speech can be reduced. Some easy governance options are to delete the hateful speech or block/suspend the hateful user. However since there is a very thin line between hate speech and freedom of speech such extreme methods may be portrayed as curbing freedom of speech. An alternative and a more favorable solution would be to use more speech (usually called counterspeech) to combat hate speech (Gagliardone et al. 2015). Different techniques of counterspeech exist -- (i) presentation of facts (e.g., citing that homosexuality is natural to fight hate speech against the LGBT community), (ii) pointing out hypocrisy involved in hate speech, (iii) warning of online/offline consequences to the hateful speaker, (iv) expression of affiliation to support victims of hate speech (v) denouncing of hateful or dangerous speech (vi) use of humor or sarcasm to inhibit hate speech and (vii) use of positive tone. In a recent work (Mathew et al. 2019c), it was shown that different techniques are effective for different hate target communities. For instance, hate speech toward LGBT community can be best combated by counter speech techniques

7. Twitter Hateful Conduct Policy. https: //support.twitter.com/articles/20175050.
8. https://www.aljazeera.com/news/2018/03/facebook-role-rohingya-genocide-180313161609822.html
9. https://www.ndtv.com/world-news/facebook-apologises-for-its-role-in-sri-lanka-2018-anti-muslim-riots-2228034
10. https://www.theguardian.com/technology/2020/jun/25/verizon-advertising-facebook-hate-speech-boycott
11. https://gab.com/

like pointing out facts and contradictions and use of humor and positive tone. On the other hand, hate speech toward the Jew community is best combated using affiliation posts and for the Black community the best way to combat through citation of consequences. However, the problem with this approach is that it is difficult to provision high volumes of such relevant counter speech since this needs involvement of a massive human taskforce. Therefore, there have been many recent efforts to automatically generate counter speech messages relevant in the context of a hate speech. Also, there are efforts to additionally incentivise human task forces to attract them to generate more counter speech.

Fake News

Fake news is intentionally and verifiably false news published by a news media agency. This has become a burning issue in the online world over the past decade and is one of the evil outcomes of the post-truth era. For instance, in the 2016 US presidential election 8,711,000 of top 20 frequently-discussed election stories on Facebook were fake while only 7,367,000 of these were real[12]. A fake article published in April 2013 about an explosion in the White House causing an injury to Barack Obama wiped out $130 billion in stock value[13]. This is even more troublesome because (i) humans have been proven to be very vulnerable while differentiating between true and false news through psychological experiments and (ii) fake news spreads faster on social media than true news. One of the reasons why the volume of fake news has got magnified is that news itself can be now produced by anyone and everyone; producing and publishing news has become easy and cheap in the online world. Finally, there is the echo chamber effect[14], i.e., a situation in which beliefs are reinforced inside a closed system by repeatedly exposing users to the same type of news which they like to anyway see; the other sides of the story remain untold/unknown to them forever. In view of the importance of the problem, there has been a lot of research for detection of fake news.

Fact Checking: One of the popular techniques is knowledge based fake news detection. The main idea here is to compare the knowledge extracted from a candidate news article and compare it against verified facts (true knowledge). This is also known as fact-checking (Dong et al. 2014) which could be either manual or automatic. Some of the very popular manually curated fact-checkers are FactCheck[15], PolitiFact[16], FullFact[17], HoaxSlayer[18], The Washington Post Fact Checker[19], Snopes[20], AltNews[21] etc. Some of these tools assign binary flags (fake or real) while others categorise the news into one of the multiple classes like 'true', 'mostly-true', 'half-true', 'mostly-false', 'false' etc. Automatic fact checking on the other hand has two parts -- fact extraction and then fact-check. Fact or knowledge is represented as a set of subject, predicate, object (SPO) triple extracted from the information at hand. For instance from the statement "Leonard Nimoy was an actor who played the character Spock in the science-fiction movie Star Trek" one can extract the following SPOs: (LeonardNimoy, profession, actor), (LeonardNimoy, starredIN, StarTrek), (LeonardNimoy, played, Spock), (Spock, characterIN, StarTrek) and (StarTrek, genre, ScienceFiction). This data extracted from millions of web resources are organized into a graph, usually called a knowledge graph (Qi et al. 2018). Examples of such knowledge graphs include Wikipedia and such others. Now when a new article is to be fact-checked SPO triples

12. C. Silverman. This analysis shows how viral fake election news stories outperformed real news on Facebook. BuzzFeed News, 2016.
13. K. Rapoza. Can 'fake news' impact the stock market? 2017.
14. https://en.wikipedia.org/wiki/Echo_chamber_(media)
15. https://www.factcheck.org/
16. https://www.politifact.com/
17. https://fullfact.org/
18. https://twitter.com/SMHoaxSlayer?ref_src=twsrc%5Egoogle%7Ctwcamp%5Eserp%7Ctwgr%5Eauthor
19. https://www.washingtonpost.com/news/fact-checker/
20. https://www.snopes.com/
21. https://www.altnews.in/

are extracted from it and compared with the SPO triples stored in the knowledge graph. Many different machine-learning approaches (Nickel et al. 2016) have been developed to execute this comparison such as latent feature based model, graph feature based model and Markov random field based model.

Style-based fake news detection: A second approach to detection of fake news has been to use style features. These include using features like the language, picture and video used in the article and construct features from these. The feature extraction is typically guided by the following principles. (i) Undeutsch hypothesis which states that content style and quality for true statements differ from the false ones. (ii) Reality monitoring which states that false claims are usually characterised by higher levels of sensory-perceptual information. (iii) Four-factor theory which states that truth manifests differently in our emotion and cognitive processes than lies. (iv) Information manipulation theory: In false statements extreme information is present in more proportions (more extreme sentiments/emotions etc.). These features can be hand-crafted to be used by traditional machine learning algorithms (Zhou et al. 2020). These features can also be latent learnt through modern deep neural networks like RNN, CNN, GCN and so on.

Propagation fake news detection: Another popular method is to analyse propagation structures of the messages to determine fake news. In an interesting study (Wu, Yang, and Zhu 2015) the authors found that rumours are usually initiated by normal users (less popular and relatively unreliable users) in the social media and catch the attention when they somehow get picked up by one or more opinion leaders (popular and reliable users) who unknowingly share and re-share the news. In contrast, true news items are typically initiated by opinion leaders which then propagates through the shares and re-shares of many normal users. The authors explicitly build message propagation trees and use the above hypothesis to correctly classify a rumour from true news.

Algorithmic Auditing

As we have already noted in the introduction, algorithmic decision-making can have many unforeseeable consequences. Since such decision-making processes are all pervasive including finance, media, transportation, education and e-commerce they can easily result in outcomes that are oblivious to even their designers. In such cases, algorithmic auditing can be one of the most effective ways to improve the design of these systems by making their consequences visible. The idea of auditing has been there in place for a long time. All companies are required to issue audited financial statements from time to time for the benefit of the stakeholders. This is because a company's internal operations are pretty much like a black box to the external world which gives unprecedented informational advantage to the company internals which could be potentially used to hurt the interests of the investing public. The current decision making algorithms that companies use (search, recommendation etc.) are also such black boxes and therefore need to be audited to avoid undesirable bias/discrimination. For instance in a recent work (Ali et al. 2019) the authors showed how the ad delivery of Facebook is skewed in showing ads to its users. To their surprise, they find that such skews are not intended by the advertisers themselves; the platform makes its own decisions based on black box algorithms to determine which users are eligible to see which ads. The authors find that the relevance of the ads are impacted by the content of the ad as well as the advertisers' budget. One of the most critical observation, which the authors note, is that gender and racial discrimination features in job and housing ads which might have alarming consequences. There has been a follow-up work where the authors audit the Facebook Special Ad Audiences tool which is advertised to mitigate sources of bias and found that signatures of bias similar to that in the earlier Lookalike Audiences tool still persists[22]. Similarly, in case of search

22. https://news.northeastern.edu/2019/12/18/facebooks-ad-delivery-system-still-discriminates-by-race-gender-age-y/

engines, Bing has been audited for differential quality of results across demographic groups (Mehrotra et al. 2017). In a very recent study (Shin and Valente 2020) the authors audit how vaccine-related books appear on Amazon based on the company's search and recommendation algorithms. They monitored the first 10 search result pages for seven consecutive days and found that the vaccine hesitant books appear twice as many times as vaccine supportive books. The three most frequently recommended books for all the seven days were vaccine hesitant. Out of the vaccine-hesitant books suggested as high as 21% of them were written by medical practitioners. Such studies should be taken up seriously in order to make the ecosystem more healthy.

Moral Machines

We are entering into an age where machines will not only be tasked to distribute the well-being they create but also to minimize the harm they will fall short to eliminate. This dichotomy of distributing both well-being and harm at the same time (of course to different receiving ends) treads the domain of moral decision making. A not-so-hypothetical situation is as follows. Suppose an autonomous vehicle is about to crash and the crash is inevitable. In such a scenario, it might have to answer whether it is going to save the three elderly passengers in it or the jaywalking youngster on the road. Such moral dilemmas are a burning problem in the modern vehicle manufacturing industries and policy makers since these cannot be resolved using Asimov's laws of robotics (Asimov 1968). Asimov's three laws are as follows. (i) A robot may not injure a human being or, through inaction, allow a human being to come to harm; (ii) A robot must obey the orders given to it by human beings except where such orders would conflict with the First Law; (iii) A robot must protect its own existence as long as such protection does not conflict with the First or Second Laws. None of these laws indicate what the robot should do if harm is inevitable. To address this challenge, the authors in (Awad et al. 2018) deployed the Moral Machine online experimental platform. The platform was developed to understand and explore the moral dilemmas that could be potentially faced by autonomous vehicles. The platform managed to gather 40 million moral decisions from users spanning across 233 countries. Different accident scenarios are generated by the platform like sparing between humans and pets, swerving and on-course movement, passengers and pedestrians, more lives and fewer lives, men and women, young and elderly, pedestrians crossing legally and jaywalking, fit and less fit etc. The authors found that at the global level the most intense preferences were sparing humans over animals, sparing more and younger lives. However, at individual country level there are certain departures observed from the global outcomes. For instance, in eastern countries like Japan and Taiwan and Islamic countries like Pakistan and Saudi Arabia, the preference to spare younger people over the elderly is far less pronounced. Likewise, in the Western countries there is only a very weak preference to spare humans over pets while a very strong preference to spare women over men. Across all territories, sparing pedestrians over passengers is weakly preferred. These observations can be taken forward by the policy makers and manufacturers to design appropriate ethical and moral guidelines for autonomous vehicles.

The Case of India

The penetration of AI enabled systems in India can have very harsh consequences. Although there have been a lot of issues related to privacy and security concerns, one issue that has been mostly underlooked is the state of the minorities. Right from the pre-independence era there existed the Criminal Tribes Act (1931)[23] in which 237 castes were identified as "criminal-by-tag". Post independence this law was replaced by the fancy Habitual Offenders Act (1952)[24]. The new act only re-stigmatised the marginalised tribes. Now imagine a police personnel using facial recognition

23. https://en.wikipedia.org/wiki/Criminal_Tribes_Act
24. https://indiacode.nic.in/bitstream/123456789/4911/1/habitual_offenders_act.pdf

techniques to do real time surveillance. In a country inflicted by casted-based and communal prejudices the concept of "suspicious person" for a policeman can be heavily biased. This can even lead to an array of tragic police killings. In quantitative terms, most of the death rows in 2016[25] were from the marginalized communities. A second concerning area is healthcare services and allocation of medical resources. In India, the doctor-patient relationship is usually one where the doctor is held in high authority and bestowed with complete trust. A large part of the patient population is illiterate and poor. Therefore, in most cases they have to accept treatment without question. In addition, the issue of obtaining informed consent from these patients is moot. Overall transparency is grossly lacking and an AI based system that is trained by medical professionals of India is only going to make this picture bleaker. A third concern is the Indian marketplace. Over the years the rising e-commerce platforms like Amazon, Flipkart etc, are heavily hurting the small-scale businesses. To add to the problem, some of these platforms, apart from acting as a marketplace, are also launching their own products/brands on their platform (e.g., Amazon private label products, Amazon prime etc.)[26]. Thus, they play the dual role of both an umpire and a player in this game. Although the Indian government is coming up with various laws to protect the interests of the small-scale businesses which is a very welcome move, yet many more newer issues are cropping up everyday which demand real time solutions[27]. We believe that one of the foremost steps in tackling all the above problems is to promote large-scale awareness programs where the mass is groomed to understand what is ethical and what is not, understand their own rights and privileges and are trained to be self-sufficient to sieve through these problems themselves and plan solutions accordingly. As a first step toward spreading this awareness, IIT Kharagpur has started a new course titled AI and Ethics[28] run by the Department of Computer Science and Engineering. The course is meant for the senior undergraduate and postgraduate students who are soon going to join the industry and should be prepared to tackle such ethical challenges. Many organizations have also come forward to spread such awareness; for instance, Facebook recently floated a grant challenge titled "Ethics in AI research India"[29] and six proposals were supported India-wide (one of these being from IIT Kharagpur)[30].

25. https://images.indianexpress.com/2016/05/07-may-2016-page-13.pdf
26. https://www.sellerapp.com/blog/amazon-private-label-products/
27. https://www.ft.com/content/29a96ff6-2615-11e9-8ce6-5db4543da632
28. http://cse.iitkgp.ac.in/~animeshm/course_aieth2020.html
29. https://research.fb.com/programs/research-awards/proposals/ethics-in-ai-research-awards-india/
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Shri Moorthy, started his career with a then MNC M/s. Crompton Greaves Ltd., in the field of power, holding various positions, gained vast experience in the field of project management, profit center, monitoring, management of change, diversification, strategic planning, business development, system development risk management etc. Was associated with developing the first private sector captive small hydro power project for M/s. Carborundum Universal Ltd., by introducing for the first time, wheeling and banking concept in India, even before power privatization was allowed. Earlier, he was instrumental in starting Petroleum, Oil and Lubricant (POL) division in M/s. Adani Exports Limited as Head and also served as Chief General Manager of M/s. Gujarat State Export Corporation Ltd, Head of Projects in Transworld Group (pioneers in coastal shipping).

He works closely with academia in facilitating a strong industry-academia connect and took leading initiative for an Indo-Austrian co-operation to carve out post graduate engineering students in the field of sub-surface engineering including air-conditioning/ ventilation etc. being currently offered at MIT Pune.

He is a passionate advocate of sustainable ecosystem of innovation, technology and promoter of aspiring entrepreneurs.

Atal Rohtang Tunnel – an Engineering Marvel

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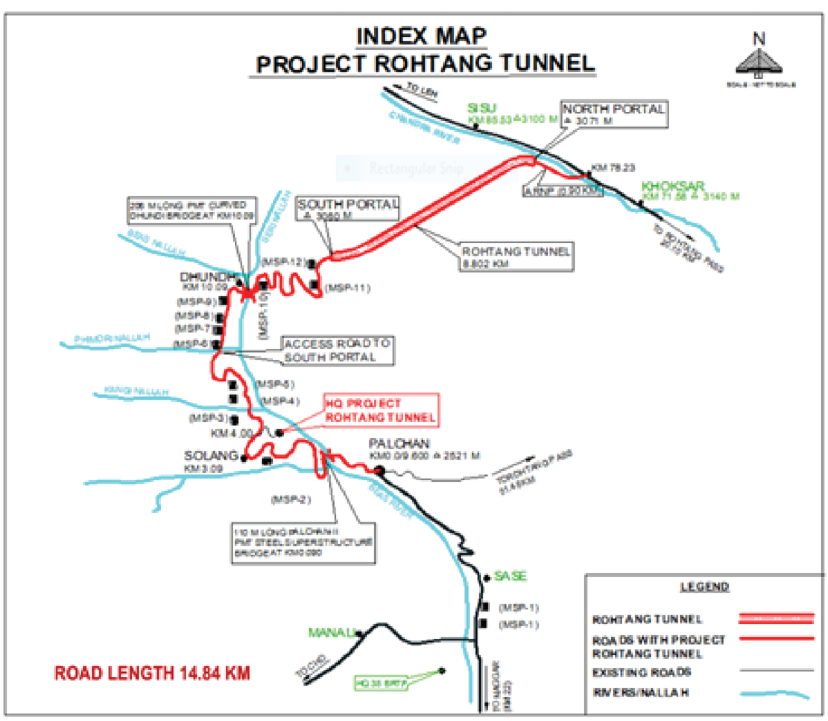
BACKGROUND

The very thought of highway drive between Manali (in Himachal Pradesh, India), and Leh-Ladakh (earlier part of Jammu & Kashmir State) kindles a feeling of adventure in everyone's heart. About 230 km of this highway drive falls under Himachal Pradesh and remaining 260 km in J&K, with a total stretch of 490 km approximately requiring a minimum of two days travel time. Almost every tourist prefers to reach Leh via Manali and take the Srinagar road for return journey. Travelling at an average elevation of nearly 4000 m (13,000 ft), with the highest point at Tanglang La mountain pass at 5,328 m (17,480 ft), is a thrilling experience for travellers. However, this road is open for about four and a half months from May/June to October every year.

Residents of Lahaul- Spiti District as well as the Indian security forces have been demanding an all-weather road since the 1980s which will facilitate them to stock up crucial supplies like food items, petroleum products, pharma products etc. including ammunition the supply of which gets cut off due to extremely bad weather conditions in winter. Rohtang Pass was the bottleneck and there goes the history.



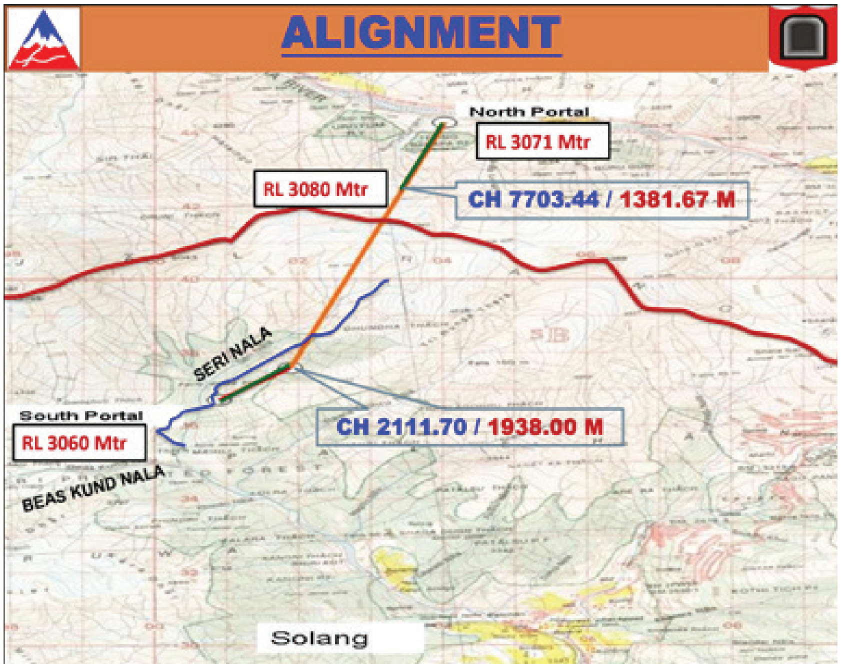


Figure: Atal Rohtang Tunnel-Location and Alignment

Rohtang Pass, at an altitude of 13,044 ft poses serious problems in maintaining the road communication for more than six months in a year due to heavy snowfall, avalanche activity, high velocity winds and sub-zero temperature. So, the idea of Rohtang Tunnel Project, now called Atal Tunnel, was first mooted by our late Hon'ble Prime Minister Smt Indira Gandhi in 1974 even though Shri Jawaharlal Nehru thought of a rope way in 1960s. However, construction of Rohtang Tunnel was conceived for the first time in 1983, when General Reserve Engineer Force (GREF), under Armed Forces Cadre of Border Roads Organisation, emphasized the need to build the Manli-Sarchu-Leh Road as an all weather route to Leh bypassing Rohtang Pass, the present road access, from strategic point of view.

A preliminary study was conducted in 1984 in consultation with Geological Survey of India (GSI) with the help of Snow and Avalanche Study Establishment (SASE) under Defence Research and Development Organisation. SASE is an organization mainly working on avalanche forecasting, artificial triggering and structural control in snowbound mountainous areas. After weighing the various alignment options, an alignment was selected for further study. The preliminary feasibility report was prepared by Geological Survey of India as a base document in the years 1983-85. Subsequently, a Border Road Development Board (BRDB) meeting chaired by then Prime Minister, Shri Rajeev Gandhi, was held on 14 January 1987, in which the proposal was deliberated upon in detail and it was decided to conduct a detailed feasibility study for construction of tunnel across the Rohtang Pass. In the year 1990, M/s BRO engaged M/s RITES (earlier known as Rail India Technical and Economic Services) to prepare a detailed project report taking into consideration the alignment suggested by GIS. M/s Rites submitted its report in 1996. After considering various options, it was finally decided that road Manali-Darcha-Padam-Nimu could provide an all weather route with a certain amount of snow clearance during winter, provided a tunnel is constructed across Rohtang Pass which was finally conceived in 1998. Finally, the official declaration of the Rohtang (ATAL) Tunnel Project was made on 03 June 2000 by our late Hon'ble Prime Minister, Shri Atal Bihari Vajpayee. A high level technical committee was constituted by the Government of India in June 2001 to examine the report submitted by RITES. Recommendations from reputed and experienced agencies like Konkan Railway Corporation (KRCL), GIS, and SASE were solicited before the high level committee submitted its report on 17 August 2001. On 06 May 2002, Indian Government entrusted the responsibility of Rohtang (ATAL) Tunnel construction to M/s. Border Roads Organisation under the Ministry of Defence, Government of India. Environment Impact Study and related study report prepared in 2004. In 2007, Snowy Mountains Engineering Corporation International Pvt Ltd, the then Australian Company was engaged as the Head Consultant to build a tunnel near Rohtang Pass with responsibility of profiling the rock structure. The lead contractor executing the Rohtang (ATAL) Tunnel for Border Roads is a Joint Venture consortium of Austrian Major Strabag and India's Afcons, a Shapoorji Pallonji Group company. The contract was awarded in September 2009.

The Project Management role as Independent Engineer was carried out by D2 Consult-ICT joint venture with major roles being played by M/s. PEMS Engineering Consultants Pvt Ltd, local partner with more than 60% share, an Aatmanirbhar visualization. Foundation stone for the project was laid by Mrs. Sonia Gandhi, the Chairperson of United Progressive Alliance on 28 June 2010 in the presence of then Defence Minister Shri. A.K. Anthony. Other organizations for ventilation, scada, seismic study, proof checking etc were also engaged by BRO.

Breakthrough of the tunnel was achieved on 15 October 2017. As the tunnel was driven from both North and South ends, for general knowledge it is called the meeting of the tunnel i.e. breakthrough, a marvellous piece of engineering excellence. Thereafter ventilation, electrical and all other allied works were undertaken. Rohtang tunnel was renamed by our Hon'ble Prime Minister Shri Narendra Modi as 'ATAL TUNNEL' as a tribute to our former Hon'ble Prime Minister Shri A B Vajpayee on 25 December 2019, Shri Vajpayee's birthday. ATAL TUNNEL, as known nowadays, was dedicated to the nation and was opened to traffic movements by our Hon'ble Prime Minister on 03 October 2020.

ATAL TUNNEL- GENERAL DETAILS

Rohtang (meaning "pile of dead bodies" in Persian language) because of life risks involved in crossing the mountain during gruelling winter months characterized by avalanches and intense snowfall. For this reason, the success of constructing the tunnel by BRO is considered as 'one of the visible oscillating feathers' in BRO's cap as well as for the Project Engineering Management Consultants for their critical role. No doubt the effort and dedication of contractors and others needs equal recognition.

Atal Tunnel is a highway tunnel built under the Rohtang Pass having height of 3978 m (13051 ft) above mean sea level. This is the longest highway tunnel in the world at this height located under the Rohtang Pass in the eastern Pir Panjal region in Himalayas at around 3048 m (10171 ft) height above sea level. It connects Manali Valley (from nearby Dhund in Kullu District) to (Gufa Hotel near Sissu) in Lahaul-Spiti District. Now travelling 71 km from north of Manali via Atal Tunnel, one can reach Keylong, the administrative headquarters of Lahaul and Spiti District. It reduces the distance between Manali to Keylong in Lahaul-Spiti District by 46 km. It takes approximately ten minutes to reach Sissu in Lahaul Spiti District from Manali. The South Portal of the tunnel is located around 25 km from Manali at a height of around 3060 m. The North Portal falls under village Teling, Sissu (near Gufa Hotel) at around 3078 m. It connects Manali to Lahaul-Spiti Valley on the Leh Manali highway. The travel time between Manali and Leh-Ladakh via Sarchu, which is around 490 km, gets reduced by four to five hours. It is also an alternative route to connect Manali – Leh (Ladakh). Traffic movements of an average 3000 cars and also 1300 trucks per day are anticipated with a speed limit of 80 kmph.

FEW ENGINEERING CHALLENGES

The construction of Atal Tunnel led to a lot of technical discussions, deliberations and thought process considering the treacherous terrain of Himalayas with snowy mountains, difficult geological and geophysical conditions needing more practical study, avalanches protection and slope studies, and other uncertain weather changes. One must also understand that this attempt of constructing a tunnel at this height in the Himalayan range is first of its kind in the world itself and so naturally too much caution prevailed among professionals including necessity, advantages, benefits, cost, life risk, etc.

Atal Tunnel is a horseshoe shaped single tube double lane tunnel. It has state of the art electro mechanical system including semi-transverse ventilation system, scada controlled for lighting, illumination and monitoring system. The tunnel is built with ultra modern specifications. New Austrian Tunneling Method (NATM) was adopted for excavating the Atal Tunnel since it provides much needed flexibility over the Tunnel Boring Machine in the event of geological and geophysical surprises that may range from finding gushing water, facing different soil strata, encountering methane deposits or even hot springs. The construction activity involved using jumbo rock drills etc as per site conditions coupled with sequential blasting. This is being followed by mucking process deploying tipper trucks, excavators etc. The excavation for tunneling was done from both North Portal and South Portal and on 15 October 2017 meeting of the both portals was officially announced.

The major challenge was to continue the excavation during harsh winter at sub-zero temperature and amidst heavy snowfall. The North Portal was not accessible at all during winter and the team faced lot of difficulties in disposing off the excavated rocks and soil. The problems were compounded by heavy ingress of water (even it touched 3 million litres per day) during June 2012 and constant dewatering proved to be a costly affair. The progress of blasting and digging were slowed down due to the unstable rocks characteristic of young fold mountains. Also, there are more than 46 avalanche sites on both approaches to the tunnel. By October 2013 a little more than 4km of the tunnel had been dug. However, at this stage about 30m portion of the roof of the tunnel collapsed towards the north portal. As a result, further digging had to be suspended temporarily till the collapse was analyzed and sorted out. Water ingress from Seri Nullah was another major issue which needed a lot of study, action plan, direction to contractors, cost analysis etc. In the Himalayan terrain, this happens to be the maiden attempt at constructing a tunnel of this length and uncertainties were beyond anybody's contemplation. Fortunately, the world's best engineering team was engaged.

TUNNEL SPECIFICATIONS

(to near accuracy)

A.	Excavation	8867 m
B	Precast - Egress	8867 m
C	Lining Arch/Final	8867 m
D	Ventilation Slab	8867 m
E	Kicker Lining	17734 m
F	Portal Building	3090 m^2

MAIN DIFFICULTY ENVISAGED AND SALIENT FEATURES OF ATAL TUNNEL

Atal Rohtang Highway Tunnel in Himachal Pradesh, India is geologically located in the central crystalline zone,, The South Portal of the tunnel is established at an altitude of 3 .055 m above sea level, approx. 25 km north of Manali, on the left bank of Seri Nala river, a tributary of Beas-Kund River. The North Portal is located across the Rohtang Pass on the left bank of Chandra River at an altitude of 3.080 m above sea level, at an approx. distance of 79 km from Manali on the Manali-Sarchu road (NH 21). Considerable care and attention was needed during execution, mainly because in this zone there is distortion of earth's crust due to forces within it causing structural deformation (tectonic) , a major element of the Himalayas.The main tunnel axis is aligned in North East direction. Unfortunately, most of the important lineaments (faults) are oblique to the main axis and thus the conditions are not favourable for tunnel excavation. The geology and geo-physcial details were one of the key base documents.

Geotechnical Investigation and Interpretations on the Atal Tunnel project could only be executed to a limited extent due to accessibility problems caused by the difficult terrain condition within the project area. A total of four boreholes were drilled along the tunnel alignment, out of which three are located close to the South Portal and one in the area of North Portal. In addition, two exploratory drifts, one at each South Portal and one in the area of North Portal. were excavated. In order to have more comprehensive information the satellite imagery was used for assessing various geological structures. Based on these geotechnical studies, an interpretive geological L-section was prepared, which formed the anticipated geological conditions In-situ field tests such as permeability tests, hydro-fracturing tests in boreholes, flat jack tests in drifts and over coring stress measurement in drifts were also conducted at the time of geotechnical investigation. The results of that investigation formed the established Rock Mass Classification, for calculating rock. The NATM method was decided for execution.

While excavating the tunnel, from the South Portal "Seri Nullah Fault Zone" issue was encountered, approx. at chainage 1 +900 in April 2012. The extremely weak condition and continuous heavy inflow of water as explained.resulting in slough (meaning a situation characterised by lack of progress or activity.)The excavation of Top Heading through this fault zone upto ch. 2+462 was difficult and lasted long. The bench and deep invert excavation of that stretch was completed with focussed attention. The tunnel drive at the north portal has been executed under high stress and squeezing rock condition including burst/ spalling generally through quartzite, gneisses, phyllites usually supplemented by Mica schists. The Tunnel of Top Heading excavation crossed the highest overburden of the Project - almost 1.900 m of cover - in summer 2015. Suitable support of Primary Lining with Lattice Girders, Rock Bolts, Wire Mesh and Shotcrete (plain shotcrete or fibre shotcrete) and sometime yielding elements -Lining Stress Controllers (LSC) - have been installed. After that the critical works of the execution of Bench and Deep Invert excavation at Seri Nullah Fault Zone were completed. . The works was completed by installing the final lining as well as E&M installation, ventilation etc.

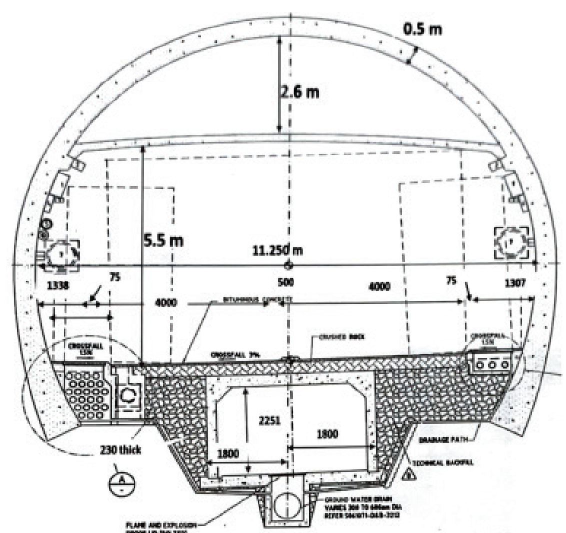


Figure: Cross section of the tunnel

GENERAL ADVANTAGE

The advantageous features associated with Atal tunnel are as follows:

- Considerable fuel cost saving and lesser pollution
- All-weather connectivity if properly snow removals are done outside the tunnel during winter
- Big scope for expansion and providing momentum for the Tourism industry and thereby employment
- Food processing, farming, pharmaceutical industry etc who are already in Himachal will get a further boost

FEW PHOTOGRAPHS OF ATAL TUNNEL

- ❖ Agro crops like peas, potatoes, apples etc. will attract more direct buyers. Wastage can be considerably reduced
- ❖ Emergency health care can be addressed better and some hospital business opportunities may emerge
- ❖ Once the tourism industry booms, connected activities like travel bookings, taxis, restaurants, guides, entertainment locations etc will also see growth
- ❖ Ropeway business as attraction to tourists can be developed
- ❖ With the help of Indo Tibetan Border Police (ITBP), Himachal is planning helipads in areas bordering China to further attract investments
- ❖ For both BRO a harbinger (forerunner) and Govt. of India Atal Tunnel completion charges confidence to attempt more.

For Lahaulis, it is a dream coming true and also for our security forces. We need to acknowledge everyone involved in the project or their commendable services, especially BRO and the Engineers, who continued their hawk-like vigil to successfully complete one of the world's prestigious engineering assignments entrusted to them. The successful completion of this engineering marvel will encourage Govt. of India to involve BRO more often in challenging projects who are dedicated to the services of the nation.

Er Narendra Singh
President, IEI

Author's Profile

Er Narendra Singh has a degree in Civil Engineering from MNNIT Allahabad and Post Graduated in Irrigation & Hydro from University of Roorkee. Er Narendra Singh served Govt. of Uttar Pradesh & Uttarakhand Irrigation Department with distinction and has vast experience in project implementation. Er Narendra Singh was instrumental in successful rehabilitation of rural and urban families affected by the construction of Tehri Dam Project (1000 MW) and his deft handling of this sensitive issue have won him accolades.

Er Narendra Singh has been recognized, through various awards, for his contribution to the engineering profession as well as for his involvement in social causes and community development. He is actively involved in various professional bodies and had been Executive Member of All India Engineers Federation and Member of National Institute of Hydrology (India) as Life Member. He is active in the education sector and interests include horticulture focused on creating a green environment.

Er Narendra Singh has rendered exceptional service to The Institution of Engineers (India) in various capacities and has been a major contributor in various initiatives undertaken in enhancing the role, relevance and image of the Institution. Er Singh is currently the President of The Institution of Engineers (India).

India's Largest Heavy Motor Suspension Bridge (Dobra-Chanthi Bridge) Over Tehri Dam Reservoir – A Brief Review

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The construction of Tehri Multi Hydro Project (1000 MW capacity) led to the formation o Tehri lake of length 42 km due to which many roads & bridges in Bhagirathi, Bhilangna River valleys were likely to get submerged. The area of Pratap Nagar Tehsil and some areas of Uttarkashi District got cut-off (isolated) from main stream. The infrastructure facilities i.e schools, colleges, hospitals, communities' etc. road & bridges were re-planed in those cutoff areas. On the demand of project affect people (PAF) community facilities were redesigned with approval from grievances redressal cell.

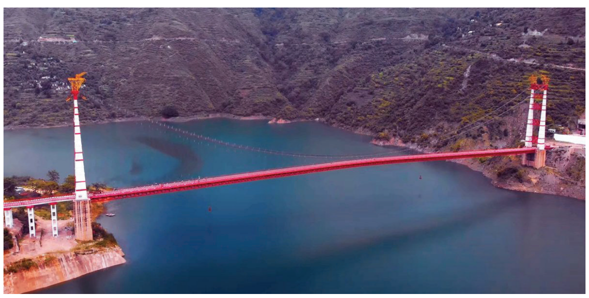
According following facilities were proposed

- Pipaldali (LMV) Suspension Bridge — 390 M span across river Bhilangna
- Ghonti (LMV) Suspension Bridge — 213 M span across river Bhilangna
- Tipri Madan Negi Rope way — 975 M span across river Bhagirathi and Bhilangna
- Dobra Chanti Bridge — 440 M span across river Bhagirathi
- Bhalyana Motna Rope way — 1024 M span across river Bhagirathi
- Siyansu Bridge (LMV) — 390 M span across river Bhagirathi
- Chinyalisod Bridge (HMV) — 165 M span across river Bhagirathi

Uttarakhand Government's unique suspension bridge, called Dobra Chanti Bridge was formally inaugurated by Hon'ble Chief Minister of Uttarakhand on 08 November 2020. In 2005, the site selection of this bridge, reconnaissance survey, DPR etc. were planned and prepared by the author who was the then Executive Director (Rehabilitation) Tehri Hydro Project. All the site investigation, geological investigation for main towers and wind anchor blocks were done by Prof. Satyendra Mittal of IIT Roorkee. Due to certain unforeseen hurdles the bridge was not completed in time, but it took approximately 15 years to complete.

The matching between the site selection and social-economic reasons of the local area were not so easy to handle but directorate of rehabilitation and PWD could surpass all the difficulties encountered in the execution of this project. The initial design was done by IIT Roorkee, but later a Korean firm completed the final design work of this bridge.

After the construction of Tehri Dam project in Tehri Garhwal District of Uttarakhand state, the Pratap Nagar Tehsil situated on the left bank of River Bhagirathi was cut off from District Headquarters Tehri in January 2006. The heavy vehicles had to travel about 150 km to Pratapnagar, which has



now been reduced to 68 km after the construction of the bridge.

The salient features of this project are as follows:

Main span	-	440 Meter suspension bridge (heavy motor)
Access bridge	-	260 + 25 meter
Total length	-	725 meters
Bridge construction starting period	-	04/ 2006
Bridge construction End period	-	09/ 2020
Total construction cost	-	Rs. 295.92 Cr

Construction work of the said bridge was approved in the year 2006 for a total length of 532 meters with a cost of Rs. 89.20 Crores by Government Order, dated 17 April 2006. Later, after studying from the point of view of the complexities and safety of the construction site, the total length of the said bridge was enhanced to 760 meters, with the main bridge being 440 meters long and 320

meters viaduct on either side. Accordingly, the revised approval was given by Government on 08 December 2008 for the escalated cost of bridge which stood at Rs. 128.53 Cr. The construction of the bridge was stopped in the month of May 2014 due to the complexities of the design of the various components during the construction of the bridge.

The total length of the project is 725 meters. The balance works of bridge were done through joint venture of the firms, namely, Yoshin Engineering Corporation of South Korea and VKS Infratech Management Pvt. Ltd., Delhi for the design, construction supervision and quality control of the bridge.

After the delay in tower retrofit works, the main bridge was completed in the month of September 2020. After the completion of final profile checking, load testing etc. by the first week of October 2020, the bridge was inaugurated on 08.11.2020 by Hon'ble Chief Minister of Uttarakhand, Shri Trivendra Singh Rawat.

After completion of bridge work, post construction phase work along with structural behavior, observation analysis and monitoring work of

bridge are now being done by consultant which will continue till December 2020.

This heavy vehicle swing bridge is the longest bridge of 440 meters in the category of high altitudes bridges the country. The width of the bridge is 5.50 meters with sidewalks of width 0.75 meters constructed on either side. State-of-the-art lighting is provided on the bridge. This unique bridge built on Tehri Reservoir has become an important tourist attraction with tourists visiting the bridge to witness the engineering marvel.

After construction of bridge, more than 1.50 lakh population of Pratapnagar area under Uttarkashi District are getting benefitted.

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Author's Profile

Shri Pradeep Chaturvedi, an Automobile Engineer, is a globally known energy and environment expert and a futurist. He is a Fellow of the Indian National Academy of Engineering, The Institution of Engineers and several other professional institutions. He is deeply involved in finding engineering solutions for attaining SDGs. His involvement with professional engineering activities is well recognized. He is Chairman, Inter-disciplinary Coordination Committee of IEI. He had planned and executed installation of the first Renewable Energy Village in India, at village Achheja, near Delhi. Shri Chaturvedi has been involved with action-oriented innovative projects on sustainable development strategies, energy and environment, policy and planning (especially the climate change) in India and other Asian and Pacific countries, all under United Nations programmes. Some of these projects are first time initiatives.

He is recipient of several national and international awards and has authored eight and edited 30 books on energy and environment.

Evolution of Society 5.0

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INTRODUCTION

A concept emerged in 1990s of realising a Super Smart Society–a "Society where various needs of society are finally differentiated and met by providing the necessary products and services in the required amounts to the people who need them, when they need them, and in which all the people can receive high quality services and live a comfortable, active life".

The process of 'nurturing as a concept' has points in common with the concept of the 'National Innovation System', which everyone today recognises as a key concept of innovation. National Innovation System tried to capture institutional mechanisms that generate innovation as a system of interactions by various actors such as companies, universities, and governments; but it did not take such a concrete form from the beginning. It appeared as an issue in OECD Science and Technology Policy in the 1990s and it was conceptualised over time through back-and-forth discourses between 'innovation' and 'policy'. It could not be grasped from linear models of innovation. By bringing a systemic view point, experts deepened their ideas while constructing an overall picture of innovation process consisting of interactions involving actors.

In the same way, experts in Japan conceptualized Society 5.0 with focus on human beings, providing as a shared concept. It would involve a wide variety of actors that in the past have only participated in non-visible ways. Participation not limited to experts, but the society as a whole was considered, especially women and young people, who would be responsible for Japan's future endeavours. In the Fifth Science and Technology Basic Plan, Japan has created space for accommodating various bottom–up ideas, demonstrating a world with roof for dreams.

Each constituency of a nation or organisation would be equipped with the ability necessary for development and change and be able to explore fully this ability. It is important to increase the number of people working under their own initiative and acting as game changers. In Japanese society today, these people are constrained by existing norms and practices and, in some respects, find it difficult to manifest their own strength. From now on, places would be created where people with a willingness to change society can pursue towards doing so by their own initiative. Such efforts are vital to realising Society 5.0.

SOCIETY 5.0: EVOLUTION

The global society is passing through a new era, one in which innovation driven by enabling technologies such as IoT, AI, and Robotics are bringing significant changes to the economy and society. In anticipation of global trends emerging out of the UN Declaration in 2015 that Sustainable Development Goals shall be achieved by the year 2030, Japan, in January 2016, decided to present Society 5.0 as a core concept for the Fifth Science and Technology Basic Plan. It was identified as a strategic part of the 'Basic Policy on Economic and Fiscal Management and Reform 2016', and furthermore as one of the growth strategies for the 'Council on Investments for the Future', which was established in September 2016 to nurture innovation strategy to enhance Japan's growth potential.

In order to understand the rationale behind promoting the concept of Society 5.0 by the Japanese government and its vision of the society on which Japan's future nation will be built, the following three major elements have to be understood:

1. Creating innovation that helps solve social challenges
2. Always the core is people, not technology
3. Goal of Society 5.0 is an innovation ecosystem.

Over-flowing of information to store, identifying the relevant and real data for analysis, and restricted scope of action due to low physical ability and lack of law and policies are creating a strain on current industrial, economic and social infrastructure of the nations, preventing societies from taking adequate measure to resolve any critical issues in time. Increasing globalization and life span, progressing economies, international competitions, social and regional inequalities, are further complicating the situation. Sustainability across the industries, green energy, climate control, and social innovation are the need of the hour.

The tremendous potential of the Industry 4.0 Revolution is paving way for nations to embrace Society 5.0, the future reality as a stepping stone to a prosperous data-synchronized super smart human-centred society. Social innovation is combining new technologies like IoT, AI, Robotics, and Big data with advanced analytics will usher in a progressive and prosperous society.

People, things, and systems are all connected in initiating the evolution of Society 5.0, converging cyber space, and physical space by collecting 'big data' from various sources through sensors and devices. 'Big data' is analysed to integrate back into physical space, with new values through various forms and media for people, industries, and corporations to achieve both economic development and solutions to social problems in parallel.

In Society 5.0, the new value created through social innovations eliminates regional, age, gender, and language gaps and enables the provision of products and services customised to various individual requirements and potential needs. It demonstrates potential to resolve a variety of challenges, in various fields such as mobility, healthcare, agriculture, food, manufacturing, disaster control, energy and many more.

Society 5.0 concept fully integrates with the vision of a Sustainable Society where everyone can live a safe and fulfilling life with a robust and comprehensive portfolio, diversity of digital solutions, and integrated approach. The industry in India is equipped to work with the government in achieving this reality by developing a robust framework for a smooth transition to Society 5.0 and help resolve various social challenges through new-age digital technologies. Hitachi (from Japan) is partnering with the Government of India in "Digital India Initiative", towards realising, structured and inclusive growth in finance, agriculture, urban development and e-governance in driving India to be equipped to meet demands of Society 5.0 in the future.

CREATIVE INNOVATION THAT HELPS SOLVE SOCIAL CHALLENGES

Dramatic changes that are fundamentally transforming society and the innovation that is bringing them about are important. Organisation for Economic Cooperation and Development, OECD, played a leading role in triggering this, and in 2010, an "innovation strategy" was formulated and positioned as the core of OECD growth strategy. At the same time UNESCO undertook major task of defining Engineering for the Future and came out with a Report in 2011 where role of engineering with concern for the mankind was highlighted. OECD's innovation strategy is inclusive and not limited to developed countries such as Japan. Movements are accelerating, relying on the complementarity between science and technology (S&T) and innovation to fuel economic growth. Even in developing countries, efforts towards bottom-up advancement of frugal innovation and inclusive innovation leading to economic growth are becoming a trend. Furthermore, in September 2015, the United Nations adopted the 2030 Agenda for sustainable development, with Sustainable Development Goals (SDG) as its core. In attaining SDGs innovation will play a central role in addressing challenges. This approach appears more relevant in post COVID-19 era.

The Government of India has also realised the role of science, technology and innovation in socio-economic development and has drafted a policy on the same. The Draft Science, Technology, and Innovation Policy (STIP 2020) was flagged-off jointly by the office of Principal Scientific Advisor and the Department of Science and Technology of India. The new policy is expected to be released by the end of 2020, replacing the existing policy which was formulated in 2013.

STIP 2020, formulation process is organised into four highly interlinked tracks, which reached out to around 15,000 stakeholders for consultation. Track-I involved an extensive public and expert consultation process through Science Policy Forum – a dedicated platform for soliciting inputs from larger public and expert pool during and after the policy drafting process. Track-II comprises experts – driven thematic consultation to feed evidence – informed recommendations into the policy drafting process. 21 focused thematic groups have been constituted for this purpose. Track-III involved consultations with Ministries and States, while Track-IV constituted Apex Level Multi–stakeholders' Consultation.

Under existing circumstances, new technologies and services are also created one after another through new combinations and/or integration into the system of existing technologies, and the world has been undergoing substantial transformation with innovation as driving force. Yet, while this has greatly enhanced lifestyle, it has also increased social complexity, and some negative aspects of our new digital society are becoming apparent. Taking a cue from the current situation in Japan, we need to address the issue of reduced involvement of labour in productivity which is expected to become more severe in the future with reduced human intervention. Strengthening industrial competitiveness thoroughly is becoming an urgent task as well. It has become all the more important after COVID-19.

Experts agree that the future development will not be technology-centred alone but human-centred. The technological developments need to be more humane, sustainable and at the same time innovative for realising the dream of a more technologically resilient and progressive society.

WHAT IS SOCIETY 5.0?

Defining Society 5.0 is not easy. It is necessary to take a long term view of history. There have been four earlier stages of evolution as enumerated below:

1. Society 1.0 as groups of people hunting and gathering in harmonious co-existence with nature
2. Society 2.0 as farming groups based on agricultural cultivation, increasing organisation and nation building marking human transformation from a food gatherer to a food producer
3. Society 3.0 as the society that promoted industrialisation through the industrial revolution, making mass production possible
4. Society 4.0 as an information society that realises increasing added value by connecting with intangible asset as information networks.
5. Society 5.0 is an information society built upon Society 4.0 aiming for prosperous human centred society.

The concept of Society 5.0 is in consonance with Japan's challenge of an ageing population. "Social Reform (innovation) in Society 5.0 will achieve a forward looking society that breaks down the existing sense of stagnation, a society where members have mutual respect for each other, transcending of generations, and a society in which each and every person can lead an active and enjoyable life", according to a White Paper from the Cabinet Office, of the Government of Japan.

Japan is creating a mechanism through Regulatory Sandboxes to provide a new de-regulation machinery to test emerging technologies such as – self driving cars, long range drones, piloting rule changes – this new system will foster experimental studies in evolving technologies such as IoT, AI, Big-data, unmanned flight and automatic driverless vehicles thereby clearing a path through cumbersome regulations. Indian IT professionals will be able to test new technologies in Japan with supportive government regulations. The Japanese Government plans to simplify and clarify pre-approval procedures for testing next generation technologies to move from theory to practice.

The technology will continue to emerge and disrupt business and markets as well. Into 2020 and beyond, technology will be channelized as a corner-stone for the interesting concept called Society 5.0. Look at society as a human-cantered reality with sustainable blend of economic and social progress, and technology cyber space and the human physical space. Initial work in Japan will demonstrate how the society is enabled as a whole to leap into smart and intelligent period.

The challenge will be to ensure that no human gets replaced by machines. Artificial Intelligence, data analytics and intelligence, and other emerging technologies will provide a plethora of choices in medical care, in agricultural production and distribution to eliminate hunger, in autonomous transportation (including automated drone technology) for logistics. Sensors, robots and automated systems will enable infrastructure to predict requirements, safeguard risks and enhance efficiency. Environment-friendly technology will fulfil energy requirements. An employment opportunity in these areas will boom.

SOCIETY 5.0 NEEDS AN INNOVATION ECOSYSTEM

Access will be the primary strategy. Digital technologies will be delivered at micro levels across locations to positively impact everyday life and activities. Focus will be on connecting, collaborating, transacting, and information sharing. Value will be created across all sectors with simpler and robust data ecosystems. It will be ensured that data is efficiently aggregated, processed and transformed into cutting edge intelligence in real time. Future will be an eco-system where people and technology leverage each other to drive infrastructural, economic and social needs.

Research between industry and academia will have to be promoted, involving the creation of innovation and ecosystems including ventures and the like. Merely having different organisations such as companies and universities follow a research plan for producing results is no different from conventional collaborative research. Innovation arises in unexpected places, and it is believed that coming across people in various fields promotes visualisation and identification of newer opportunities, much like in a wide open natural ecosystem. Such soft forms of cooperation are the basis for an innovation ecosystem. What will be important is the extent to which we can build mutually inspiring relationships while maintaining a higher degree of freedom, without being limited to formal industry – academia collaboration? How to build so-called social capital that regards such relationships as an asset will be the prime mover for innovation.

FOSTERING INNOVATIVE ECOSYSTEM: ROLE OF PRIVATE PLAYERS

The world has passed through industrialisation and then through digitalization accentuated by breakthrough developments providing an age of convenience and healthy living. Of course there have been negative aspects accompanying scientific and technological advancement. There has been an undesirable increase in inequality. We have arrived at a time for engagement in social issues not just by a few selected specialists and politicians but by everyone. Private enterprises have a social responsibility to demonstrate leadership through their human resources, funds, networks and extensive technologies and expertise. This will be an evolving ecosystem where all societies will have to play their part.

Incentives will be created for workers to voluntarily invest in capabilities. Prior learning and apprenticeship interventions will be effectively leveraged to give employers the right employment generating information that makes vast numbers of informal workers employable.

CONCLUSION

Society 5.0 is a vision of a human-centric approach in technology development and application. This concept is aimed at employing latest technologies to provide crucial safe and sound socio-economic model of human development. Technology will not necessarily displace all human intervention but will make it more effective. As the life expectancy is increasing the globe will be inhabited by larger number of aging population needing healthcare, nutrition and habitation services. Technology will ensure that persons of all age groups enjoy quality services leading to useful living. Society 5.0 will be based on AI, IoT and digital platforms where engineers will have a crucial role.

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