FAST INDIA

Office of the Principal Scientific Adviser to the Government of India

A DECADE OF SCIENCE

Technology Panorama for **Aatmanirbhar Bharat**

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CREDITS

Office of the Principal Scientific Adviser to the Government of India
Dr. Parvinder Maini, Scientific Secretary
Dr. Sneha Malhotra, Chief Technology Officer

FAST India

LEAD
Mudit Narain

EDITORS
Anjana Seshadri
Harleen Kaur

AUTHORS
Harleen Kaur
Anjana Seshadri
Kaustubh Misra
Chetandeep Singh
Vibodh Nautiyal

Design and Layout
CREATIVE DIRECTION & DESIGN
Tanmay Gupta *(Connect)*

INTEGRATED CREATIVE DESIGNER
Isha Choudhary *(Connect)*

Year of publication
2024

Published by
Office of the Principal Scientific Adviser to the Government of India
Vigyan Bhavan Annexe,
Maulana Azad Road,
New Delhi – 110011
Phone: 011 23022038 | Fax: +91 11 2302 2113

Foundation for Advancing Science and Technology (FAST India)
The Convergence Foundation,
242, Okhla Industrial Estate Phase 3 Rd,
Okhla Phase III, Okhla Industrial Estate,
New Delhi - 110020
Email address: info@fast-india.org

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Acknowledgements

This report has been jointly prepared by the Office of the Principal Scientific Adviser to the Government of India (OPSA), and the Foundation for Advancing Science and Technology (FAST India).

We would like to thank the following Ministries, Departments and Institutions which have provided valuable inputs and feedback for the content of this report. A list, in no particular order is presented below:

List of Ministries and Departments

National Institution for Transforming India (NITI Aayog)

Ministry of Electronics and Information Technology (MeitY)

Ministry of Coal

Ministry of Agriculture & Farmers Welfare

Ministry of Earth Sciences (MoES)

Ministry of Civil Aviation (MoCA)

Ministry of New & Renewable Energy (MNRE)

Department for Promotion of Industry and Internal Trade (DPIIT)

Department of Science & Technology (DST)

Department of Atomic Energy (DAE)

Department of Biotechnology (DBT)

Defence Research and Development Organisation (DRDO)

Department of Space (DoS)

Department of Animal Husbandry & Dairying (DAHD)

Department of Telecommunications (DoT)

Council of Scientific & Industrial Research (CSIR)

Indian Council of Medical Research (ICMR)

Biotechnology Industry Research Assistance Council (BIRAC)

Bhabha Atomic Research Centre (BARC)

Indian Space Research Organisation (ISRO)

Ministry of Railways

Department of Financial Services

LIST OF ABBREVIATIONS

ABHA - Ayushman Bharat Health Account
ACC - Advanced Chemistry Cell
ACICs - Atal Community Innovation Centres
AEPS - Aadhaar Enabled Payments System
AgriGVA - Agriculture Gross Value Added
AI -Artificial Intelligence
ANRF - Anusandhan National Research Foundation
AIF - Agri Infrastructure Fund
AIM - Atal Innovation Mission
AIRAWAT - AI Research, Analytics and Knowledge Assimilation
AM - Additive Manufacturing
APIs - Application Programming Interfaces
ART - Atmospheric Research Testbed
ASCEND - Accelerating Startup Calibre & Entrepreneurial Drive
ATL - Atal Tinkering Labs
AICs - Atal Incubation Centres
AUV - Autonomous Underwater Vehicle
BIG -Biotech Ignition Grant
BIS - Bureau of Indian Standards
BIRAC - Biotechnology Industry Research Assistance Council
BMS - Battery Management Systems
BSF - Border Security Force
BSNL - Bharat Sanchar Nigam Limited
CAGR - Compound Annual Growth Rate
CCMB - CSIR-Centre for Cellular and Molecular Biology
CCP - Cold Chain Points
C-DAC - Centre for Development of Advanced Computing
C-DOT - Center for Development of Telematics
CDSCO - Central Drug Standard Control Organisation
CEPI - Coalition for Epidemic Preparedness Innovations
CERN - Conseil européen pour la Recherche Nucléair or European Organization for Nuclear Research
CHCs - Custom Hiring Centres
CISF - Central Industrial Security Force
CNPN - Captive Non-Public Network
COP - Conference of Parties
CoWIN - COVID-19 Vaccine Intelligence Network
CRISPR - Clustered Regularly Interspaced Short Palindromic Repeats
CRPF - Central Reserve Police Force
CRS - Central Receiving Station
CSIR - Council of Scientific and Industrial Research
DAE - Department of Atomic Energy
DAP - Defence Acquisition Procedure 2020
DBT - Department of Biotechnology
DBT - Direct Benefit Transfer
DCSEM - Department of Atomic Energy Directorate of Construction Services and Estate Management
DGCI&S - Directorate General of Commercial Intelligence and Statistics
DISC - Defence India Startup Challenges
DPGs - Digital Public Goods
DPI - Digital Public Infrastructure
DPIIT - Department for Promotion of Industry and Internal Trade
DST - Department of Science & Technology
EGoS - Empowered Group of Secretaries
ESS - Energy Storage Systems
EUL - Emergency Use Listing
eVIN - Electronic Vaccine Intelligence Network
EVs - Electric Vehicles
E-YUVA - Empowering Youth For Undertaking Value-Added Innovative Translational Research
FAME - Faster Adoption and Manufacturing of (Hybrid &) Electric Vehicles
FDI - Foreign Direct Investment
FLOPS - Floating Operations Per Second
FLWs - Frontline Workers
FMCG - Fast-moving Consumer Goods
FPO - Farmers Producers Organisation
GDP - Gross Domestic Product
GeM - Government e-Marketplace
GERD - Gross Expenditure on Research & Development
GIS - Geographic Information System
GNSS - Global Navigation Satellite System
GPAI - Global Partnership on AI
GPS - Global Positioning Systems
GSLV - Geosynchronous Satellite Launch Vehicle
GVA - Gross Value Added
GII - Global Innovation Index
HEI - Higher Education Institutes
HGFM - High-Resolution Global Forecast Model
HPC - High-performance computing
HPV - Human papillomavirus
HRD - Human Resource Development
HSFC - Human Space Flight Centre
ICDS - Integrated Child Development Services
ICT - Information and Communications Technology

iDEX - Innovations for Defence Excellence
IDP - India Datasets Platform
IITM - Indian Institute of Tropical Meteorology
IMCC - Inter-Ministerial Coordination Committee
IMT - International Mobile Telecommunications-2020 Standards
INAPH - Information Network for Animal Productivity and Health
INCOIS - Indian National Centre for Ocean Information Services
inSPACE - Indian National Space Promotion and Authorization Center
INSPIRE - Innovation in Science Pursuit for Inspired Research
IOC - Intergovernmental Oceanographic Commission
IoE - Institutions of Eminence
IoT - Internet of Things
IOTWMS - Indian Ocean Tsunami Warning & Mitigation System
IPO - Initial Public Offering
IPR - Institute for Plasma Research
IPR - Intellectual Property Rights
ISRO - Indian Space Research Organisation
ITBP - Indo-Tibetan Border Police
ITER - International Thermonuclear Experimental Reactor
ITEWS - Indian Tsunami Early Warning System
ITU - International Telecommunication Union
IUCAA - Inter-University Centre for Astronomy and Astrophysics
KCC - Kisan Credit Card
KYC - Know Your Customer
LEO - Low Earth Orbit
LHC - Large Hadron Collider
LIDAR - Light Detection and Ranging
LIGO - Laser Interferometer Gravitational-Wave Observatory
LMLC - Low-Mobility Large-Cell
MeitY - Ministry of Electronics and Information Technology
MERA - Multi-Ensemble Rainfall Analysis
MGB - Mission Governing Board
MHVM - Multi-hazard Vulnerability Mapping
MIDH - Mission for Integrated Development of Horticulture
MIT - Massachusetts Institute of Technology
MSMEs - Micro, Small, and Medium Enterprises
MSP - Minimum Support Price
NAIP - Nationwide Artificial Insemination Programme
NASSCOM - National Association of Software and Service Companies
NavIC - Navigation with Indian Constellation
NBHM - National Beekeeping and Honey Mission
NBM - National Broadband Mission
NCAM - National Centre for Additive Manufacturing
NCL - CSIR-National Chemical Laboratory
NCMRWF - National Centre for Medium-Range Weather Forecasting
NEMMP - National Electric Mobility Mission Plan
NGP - National Geospatial Programme
NIJ - National Institute of Justice
NITI Aayog - National Institution for Transforming India
NIVEDI - National Institute of Veterinary Epidemiology and Disease Informatics
NIV - ICMR-National Institute of Virology
NMEO - National Mission for Edible Oils
NM-ICPS - National Mission on Interdisciplinary Cyber-Physical Systems
NMP - National Master Plan
NMSA - National Mission for Sustainable Agriculture
NPG - Network Planning Group
NPCI - National Payments Corporation of India
NQM - National Quantum Mission
NSF - National Science Foundation
NSIL - NewSpace India Limited
NSM - National Supercomputing Mission
NSN - National Seismological Network
ONDC - Open Network for Digital Commerce
ONOS - One Nation One Subscription
PARAM - PARAllel Machine
PDMC - Per Drop More Crop
PEMFC - Proton Exchange Membrane Fuel Cell
PKVY - Parampragat Krishi Vikas Yojana
PLI - Production-Linked Incentive
PMFBY - Pradhan Mantri Fasal Bima Yojana
PM-POSHAN - Pradhan Mantri Poshan Shakti Nirman

PMRF - Prime Minister's Research Fellows
PMU - Project Management Unit
OPSA - Office of the Principal Scientific Adviser
PSLV - Polar Satellite Launch Vehicle
QPM - Quality Planting Material
R&D - Research & Development
R-ABIs - RKVY Agribusiness Incubators
RAD - Rainfed Area Development
RAN - Radio Access Network
RDDL - Regional Disease Diagnostics Laboratories
RoW - Right of Way
RPC - Remote Pilot Certificate
RRCAT - Raja Ramanna Center for Advanced Technology
S&T - Science & Technology
SAC - Scientific Advisory Committee
SAFFGS - South Asia Flash Flood Guidance System
SATHI - Seed Authentication, Traceability and Holistic Inventory Portal
SDMC - South Delhi Municipal Corporation
SEBI - Securities and Exchange Board of India
SEPs - Standard Essential Patents
SIDBI - Small Industries Development Bank of India
SITARE - Students Innovations For Advancement Of Research Explorations
SMAM - Sub-Mission on Agricultural Mechanization
SMSP - Sub-Mission on Seeds and Planting Materials
SoI - Survey of India
SQA - Square Kilometre Array
SSF - Swachhta Saarthi Fellowship
STIP 2020 - Science Technology and Innovation Policy of 2020
STI - Science, Technology & Innovation
TCO - Triangular Cubic Octahedral Grid
TCS - Tata Consultancy Services
TDP - Technology Development Program
TIFR - Tata Institute of Fundamental Research
TIHs - Technology Innovation Hubs
TPDS - Targeted Public Distribution System
TSU - Technical Support Unit
UAVs - Unmanned Aerial Vehicles
UIP - Universal Immunization Program
UNCTAD - United Nations Conference on Trade and Development
UNICEF - United Nations International Children's Emergency Fund
UPI - Unified Payments Interface
VAP - Vaccine Action Programme
VEPP - 5G Vertical Engagement and Partnership Program
VSSC - Vikram Sarabhai Space Centre
WHO - World Health Organisation

MESSAGE

सत्यमेव जयते

प्रधान मंत्री
Prime Minister

MESSAGE

The commendable initiative of preparing and publishing the report, "A Decade of Science: Technology Panorama for an Aatmanirbhar Bharat," deserves appreciation. Greetings and best wishes to the office of the Principal Scientific Advisor to the Government of India and Foundation for Advancing Science and Technology (FAST-India) for this thoughtful endeavour.

The progress made over the last 10 years in the realm of science and technology is for all to see. The work done in the last decade is helping in realising the vision of making the next ten years as India's 'Techade'.

India boasts of a rich legacy in science, technology, and innovation, with a vision to chart an even brighter future for people. Science and technology are meant serve a higher purpose - to transform people's daily lives in a tangible way. Our scientific community is doing this with their tireless work.

The report highlights India's sustained efforts in science and technology, particularly in fields such as infrastructure, defence, energy sector and heavy industries. Be it investing in cutting-edge fields like artificial intelligence, deep-sea and space exploration, Chandrayaan-3's landing on South Pole of the Moon, leadership in vaccine development during the pandemic, or commitment to expand renewable energy – all such efforts showcase our continuing journey towards self-reliance.

Our goal is to make India a premier hub for scientific learning and at the same time, learn from global best practices, as well as share our knowledge and experiences with the world.

Our scientists have carried out ground-breaking research across diverse spheres, while our tech ecosystem provides innovative solutions to global challenges. The implementation of initiatives such as Anusandhan National Research Foundation further strengthens our research capabilities.

We have also implemented far-reaching reforms in the education sector to instil a scientific temperament among our youth, as well as promote inquiry-based learning. A whole new generation of budding scientists is coming to the fore, ready to take our journey forward.

The coming years until 2047 is a period that is crucial to realise our vision of building a strong, self-reliant nation, where the scientific community in particular, especially our youth, will play a defining role. It is thus crucial for all stakeholders – ministries, scientists, educational institutions, research institutes, industry and investors - to collaborate and build an ecosystem for progress based on science & technology.

May the report facilitate a better and deeper understanding of the progress and achievements in the field of science & technology over the last decade. May it inspire more such work in the future.

(Narendra Modi)

New Delhi
फाल्गुन 14, शक संवत् 1945
04th March, 2024

MESSAGE

अजय के. सूद
भारत सरकार के प्रमुख वैज्ञानिक सलाहकार
Ajay K. Sood
Principal Scientific Adviser to the Govt. of India

सत्यमेव जयते

विज्ञान भवन एनेक्सी
मौलाना आजाद मार्ग, नई दिल्ली - 110011
Vigyan Bhawan Annexe
Maulana Azad Road, New Delhi - 110011
Tel. : +91-11-23022112
Fax: +91-11-23022113
E-mail : sood.ajay@gov.in
office-psa@nic.in
Website : www.psa.gov.in

MESSAGE

In an era defined by rapid globalization and interconnectedness, the significance of science, technology, and innovation cannot be overstated. These pillars of progress have transcended boundaries and transformed the very fabric of our societies, shaping economies, enhancing healthcare, revolutionizing communication, and redefining the boundaries of human knowledge.

India, a land of diverse cultures, languages, and landscapes, has embraced the pursuit of scientific excellence and technological innovation as a cornerstone of its national identity. In the contemporary landscape, India's commitment to harnessing the power of science, technology, and innovation has manifested in remarkable ways. From breakthroughs in vaccine developments to strides in building next-generation digital infrastructure to advancement in space exploration, India has embarked on a journey of transformation that resonates on a global scale. In the past decade, the Government of India (GoI) has exhibited a resolute vision regarding science, technology, and innovation, highlighted by its unwavering commitment to the concept of "Atmanirbhar Bharat" or self-reliant India. This approach has catalyzed a shift from dependency on external sources to nurturing domestic capabilities, fostering innovation, and propelling indigenous research and development. This paradigm shift allowed India to harness its immense human capital, technological prowess, and innovative spirit to secure a position of strength globally.

I am delighted to present **"Technology Panorama for Aatmanirbhar Bharat"**, a comprehensive report that delves into the scientific and research endeavours, initiatives, and programs executed by India in the past decade. This report highlights the extensive scope and influence of India's commitments in the realms of Science, Technology, and Innovation.

The report examines the different missions, initiatives, and programmes through four lenses viz. *systemic capability building, pushing frontiers of research for future preparedness, enabling research and development in areas of national priorities, and ensuring citizen impact of scientific improvement*. These objectives are significant, irrespective of the nature of the research and can coexist harmoniously. The report examines the efforts in Science and Technology under subsections such as *Capability Building, Energy, Exploration, Public Service, Agriculture, Livestock and Biotechnology, and Health*.

There are over a hundred missions, schemes, programs and initiatives across multiple government ministries and departments that focus on scientific and technological research and innovation. This report chooses a compact yet potent subset of these endeavours to highlight the profound and continuous influence that science has on our lives. While this does not encompass the entirety of our nation's scientific and technological pursuits, it offers an exhilarating glimpse into the progress and innovation taking place in current times, especially in the last ten years.

I would like to acknowledge the support from all the ministries, departments and organisations who have provided their valuable inputs for the preparation of this report. I extend my appreciation to the members of the Foundation for Advancing Science and Technology (FAST) - India for their sincere efforts in putting together this report. Lastly, I wish to congratulate colleagues from my office for their effortless teamwork that led to the completion of the report.

Ajay K Sood

(Ajay K. Sood)

Dated: 1st March, 2024

MESSAGE

डॉ. वी.के. सारस्वत
Dr. V.K. Saraswat
सदस्य
Member
Tele : 23096566, 23096567
Fax : 23096603
E-mail : vk.saraswat@gov.in

सत्यमेव जयते

भारत सरकार
नीति आयोग, संसद मार्ग
नई दिल्ली - 110 001
Government of India
National Institution for Transforming India
NITI Aayog, Parliament Street,
New Delhi - 110 001

G20 समूह 2023 INDIA

MESSAGE

In the pursuit of realizing the vision of Atmanirbhar Bharat, our nation has embarked on a transformative journey, recognizing technology and innovation as the very bedrock of our progress. As we stride forward, we aim to harness the immense power of technology, innovation, and research to empower our citizens, bolster our economy, and effectively address our society's multifaceted challenges. The report is a testament to India's unwavering commitment to embracing technological innovation and achieving self-reliance in the ever-evolving digital era.

Comprising a comprehensive and meticulous analysis, this report delves into the significant strides made by the Government of India in fostering a vibrant and technology-driven ecosystem. Encompassing a broad spectrum of cutting-edge domains, such as Cyber-Physical Systems, Artificial Intelligence, Quantum Computing, Electric Mobility, Green Hydrogen, Deep Ocean Exploration, and Defence and Drone Technologies, it represents the formidable pillars upon which our vision for a technologically advanced and self-reliant India firmly rests.

The report provides a panoramic view of stakeholders' remarkable progress and transformative initiatives. From esteemed government bodies to pioneering research institutions, academia, and visionary industry partners, this collaborative effort exemplifies the collective will to advance technological excellence. Moreover, it meticulously scrutinizes the opportunities and challenges before us, forging a path for unified strategies to address these imperatives with shared determination.

The insights presented in this comprehensive report offer invaluable perspectives, poised to shape policies and investments that further accelerate our technological growth. We firmly believe that fostering interdisciplinary collaboration and knowledge-sharing across sectors will be a powerful impetus in propelling India toward its rightful place as a global technology leader.

As we navigate the intricacies of an ever-evolving technological landscape, all stakeholders must embrace a spirit of unwavering innovation, openness, and inclusivity. Together, let us work in harmonious synergy to ensure that technology becomes a formidable force for good, unfailingly creating opportunities and prosperity for all. Let us redouble our efforts in unison as we march unwaveringly toward the realization of Atmanirbhar Bharat – a self-reliant India – empowered and transformed by the indomitable spirit of technology.

With relentless determination and collective endeavour, we shall undoubtedly triumph and propel our great nation to newer heights through the transformative power of technology.

(Dr. V.K. Saraswat)

स्वच्छ भारत
एक कदम स्वच्छता की ओर

New Delhi
01.03.2024

INTRODUCTION

"The appearance of Science and Culture is to be warmly welcomed not only by those who are interested in abstract sciences but also by those who are concerned with nation-building in practice."

Netaji Subhash Chandra Bose[1]

Advancements in science and technology (S&T) lay the foundations for the advancement of humanity. The past decade has witnessed an extraordinary development in Indian scientific capabilities spurred on by digital and technological interventions. With the enabling environment created by government policies, India has pushed the frontiers of S&T while also improving the quality of life of its citizens at large. In this report, we examine some of the S&T interventions from the last decade, their design assumptions and objectives, prominent achievements, and their impact on the lives of citizens.

Historically, the Indian government has been focused on funding and doing science all by itself. Soon after independence, a large number of government higher education institutes (HEIs) and government labs for S&T were established in India.[2] However, S&T research and development occurred primarily in specialised government labs, while HEIs focussed on providing education.[3] In the past decade, efforts have been made to democratise the practice of, and enable access to science, to bring more citizens into the fold. This has resulted in the participation of startups, micro, small, and medium enterprises (MSMEs), public and private educational institutions and businesses in developing India's science and technology capabilities, thereby truly harnessing the Indian demographic dividend for creating the future of the country. The efforts of the government in improving the S&T ecosystem are recognised globally. Figure 1 below shows India's improving rank in the Global Innovation Index (GII) over this past decade.[4]

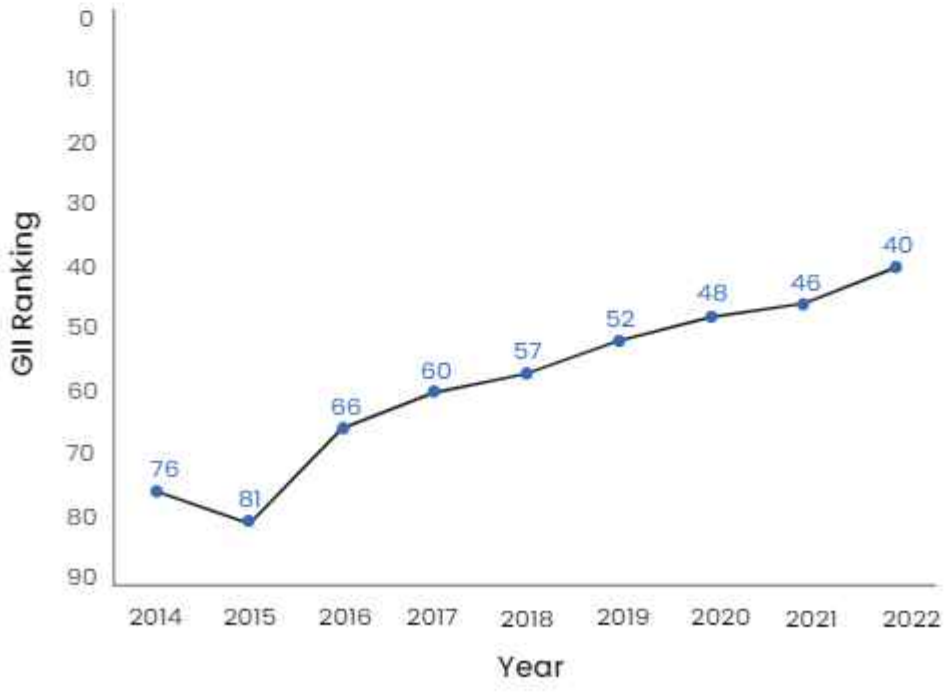


Figure 1: India's improvement in GII *(Source: GII 2022)*

"Efforts of science can turn into great achievements only when they come out of the lab and reach the land, and their impact reaches from global to grassroots, when its ambit is from journal to jameen and when change is visible from research to real-life"

Hon'ble Prime Minister, Shri Narendra Modi[5]

India is one of the top three countries in terms of the number of scientific publications, number of PhDs, the size of its higher education system, and the number of start-ups.[6] India is also fast moving towards low-cost, high-efficiency indigenous scientific developments and innovation. Indian companies and private universities now occupy the position of the top five patent applicants filed in the field of Information and technology.[7] Overall, the number of patents granted by the Indian Patent Office has been consistently rising over the years as shown in Figure 2 below.

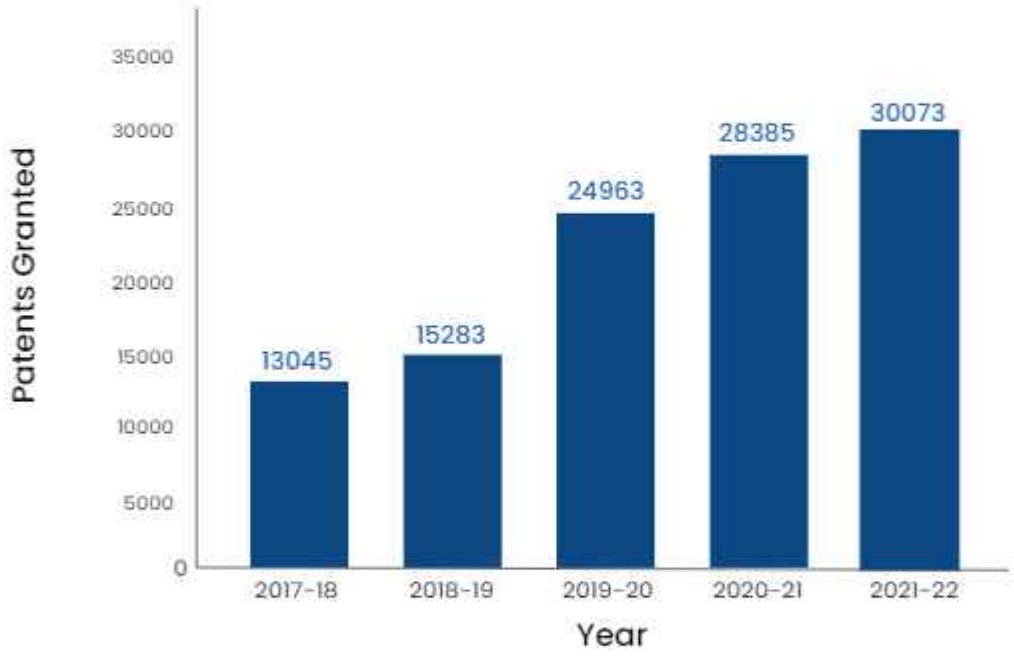


Figure 2: Number of patents granted in India *(Source: Data from Indian Patent Office, DPIIT[8])*

The Indian scientific achievements of this past decade have been a result of the unwavering focus of the government on developing capabilities for doing research for India, by India - on the lines of Aatmanirbhar Bharat, a call for self-reliance. There has been a focus on developing scientific ideas and research in a direction relevant to the public and society at large under this initiative.

While focusing on self-reliance, India is rapidly making key S&T partnerships and collaborations with other countries to improve its Gross Expenditure on Research and Development (GERD) efficiently. For instance, India recently announced collaboration on frontier technologies such as cyber-physical systems, secure and trustworthy cyberspace, and joint projects in applied research areas such as semiconductors, next-generation communication, cyber security, sustainability and green technologies with the United States (US).[9]

The Indian technology community, assisted by the systemic capability building by the government, has pushed frontiers by building national 'stacks' enabling digital India, enhancing the standard of living of citizens through improvements in communication technology, sanitation, urban transport etc., while focusing on national priorities such as defence and exploratory missions in the sea and space. However, moving forward, India needs to promote its research and development (R&D) with full force to be able to reap the benefits of the programs and missions introduced in the recent past. The Government of India (GoI) acknowledges the importance of increasing R&D expenditure and utilising the same effectively. For instance, GERD in India has been continuously increasing over the years in absolute numbers. However, as a percentage of Gross Domestic Product (GDP), GERD has been hovering around 0.7 % during the last few years and is below the world average.[10] At about 37% of the total GERD, the corporate funding for R&D in India is very low when compared to the global average.[11] Despite this, Indian scientists have managed to receive numerous accolades in and outside the country.

Most of the improvements in Indian S&T performance of the past decade can be attributed broadly to the following four forms of key interventions by the government:

- Systemic capability building,
- Pushing frontiers of technology and research for future preparedness,
- Ensuring citizen impact from scientific improvement, and
- Enabling R&D in areas of national priorities

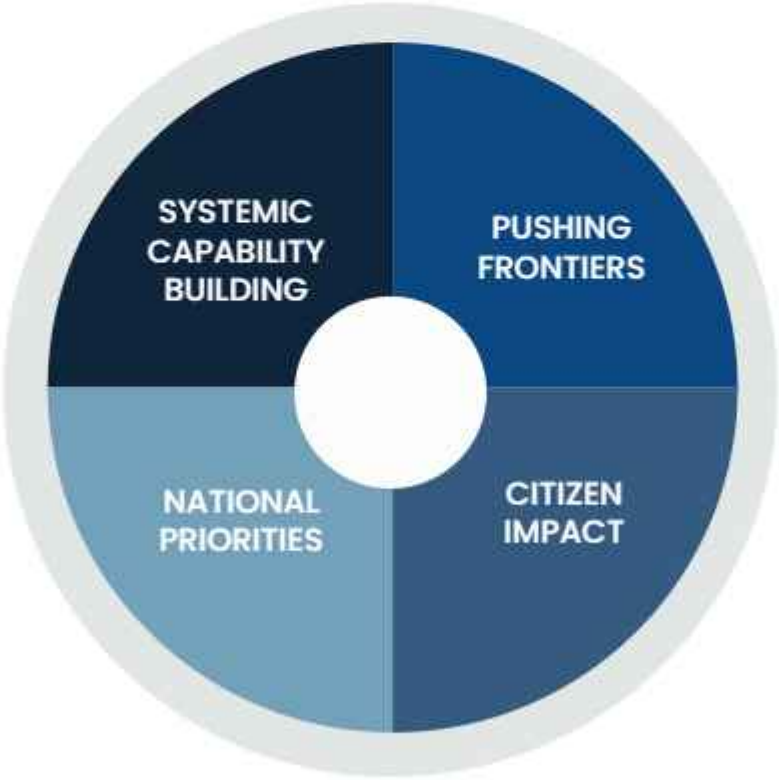


Figure 3: Forms of government interventions

PART 1

A Decade of Science: India's Advancements in Enabling and Doing Science

1. Systemic Capability Building

All countries need scientific, technological and engineering capacity to provide solutions to the sustainable development challenges they face in areas such as health, agriculture, communication, energy, industrial and infrastructure development,[12] as well as develop future industries. Using this philosophy, the Indian government focussed on supporting its institutions and resources in conducting world-class research.

The Indian government has focussed on capability building through schemes such as the Institutions of Eminence (IoE) to support HEIs to become world-class teaching and research institutions.[13] Under the IoE scheme, the recognised institutions are enabled to improve their quality of teaching and research, specialise in identified areas, and achieve recognition in global rankings by incentives such as greater autonomy and financial grants. The IoE scheme was started by the Indian government in 2017 and aims to make select Indian universities world-class.

The Indian government has also been running multiple fellowship and research programmes to promote talented individuals and research groups in conducting groundbreaking research. For instance, the High-risk-high-reward Research Scheme, supports proposals that are conceptually new and risky, and are expected to have a paradigm-shifting influence on the S&T ecosystem, if successful.[14] Similarly, the Prime Minister's Research Fellows Scheme (PMRF) provides generous scholarships to researchers conducting S&T research in the top S&T institutions of the country.[15] As of 2023, there are 2,572 fellows under the PMRF, of which about 36% are women.[16] The Ramanujam Fellowship supports researchers from outside India,[17] while the Innovation in Science Pursuit for Inspired Research (INSPIRE) attracts talent to science at an early age to help the country build the required critical resource pool for strengthening and expanding the S&T system and R&D base with a long term foresight.[18]

A deep S&T focus of the government can be seen from the fact that there are many science missions outside the purview of ministries focusing on S&T.

These include the National Bioenergy Program aimed at promoting the use of bioenergy as a sustainable and renewable energy source, and the Green Hydrogen Mission aimed at establishing India as a global hub for the production and export of green hydrogen. The Deep Ocean Mission aims to enable the development and deployment of technologies for conducting deep-sea research. India's semiconductor mission similarly aims to develop a longterm strategy for sustainable semiconductor and display manufacturing facilities for the country, with 2.5% of its budget earmarked for R&D, skill development, and training.[19] The Ministry of Jalshakti's Jal Jeevan Mission is envisioned to provide safe and adequate drinking water through individual household tap connections by 2024 to all households in rural India. The National Digital Livestock Mission has developed a unique identification number system to create a database for livestock animals wherein the complete life-cycle of animals can be captured and traceability can be established.

For industry, academia and government collaborations, S&T clusters were envisaged and developed in the past decade through the Office of Principal Scientific Adviser to the Government of India.[20] The S&T clusters operate at a city level to create strong linkages between existing academic institutions, national & state research laboratories, and other stakeholders like relevant ministries, industry partners, startups, MSMEs, state governments, philanthropic foundations, and international organisations.[21] Apart from these endeavours, they are also involved in solving regional problems.

Startup India initiative, one of the flagship initiatives of the Government of India was introduced in 2015 to catalyse startup culture and build a strong and inclusive ecosystem for innovation and entrepreneurship in India through fiscal and non-fiscal incentives.[22]

Strengthening the Indian railways' capabilities, a state-of-the-art Automatic Train Protection (ATP) system named "Kavach" has been developed with an indigenously designed anti-collision device. The system is aimed at providing automatic train protection to augment safety and capacity with the highest level of Safety Integrity SIL-4. The South Central Railway has successfully deployed the system that covers 1,465 route kilometers, serving 135 locomotives. The project is currently in progress, extending its reach to approximately 3,000 route kilometers, encompassing the critical Delhi-Mumbai and Delhi-Howrah corridors. Further, technological advancement in Kavach from the UHF frequency range to LTE/4G is underway to significantly enhance the system's reliability.

In agriculture, the National Biotechnology Development Strategy 2021-2025 outlines a comprehensive roadmap for harnessing biotechnology to address agricultural challenges, promote sustainable practices, and foster economic growth.[23]

In addition, technologies such as food irradiation are being developed by the Department of Atomic Energy (DAE) through Bhabha Atomic Research Centre (BARC) to preserve food, improve quality of fungicides and the quality of soil.

The recent passage of the the Anusandhan National Research Foundation (ANRF) Act, 2023 is slated to be one of the most significant steps taken by the Indian government since independence for the S&T ecosystem.[24] The ANRF has been established as an apex body to provide high-level strategic direction of scientific research in the country at a total estimated cost of INR 50,000 crores during five years (2023-28), which includes INR 14,000 crores from the Government of India. ANRF is aimed to forge collaborations among the industry, academia, and government departments and research institutions, and create an interface mechanism for participation and contribution of industries and state governments in addition to the scientific and line ministries.[25]

ANRF is set to improve the aatmanirbharta of Indian R&D ecosystem. In the recent past, India has shown remarkable advancements in indigenous development of nuclear energy and defence programs, and with ANRF, the innovations and developments are set to soar further. The story of India's nuclear program has been one of perseverance and scientific expertise. India is propelling towards nuclear energy self-reliance by using thorium as fuel, rather than relying only on imported uranium. The capabilities that India has built in nuclear power are the foundation to an energy secure nation, and provide learnings to other industrial and R&D sectors.

Perhaps one of the most crucial areas in which India is developing systemic capability is in defence and internal security. DRDO has developed several technologies that has advanced India's defence capabilities. These developments allow India in maintaining its strategic independence and flexibility in the developing geopolitical ecosystem.

2. Frontier Technologies and Research

Frontier technologies are those that are essential for sustainable development. The UNCTAD Technology and Innovation Report 2021 (UNCTAD Technology Report 2021) critically examines the status of frontier technologies across the globe to develop a "readiness index" for frontier technologies. The report comprises five building blocks: ICT deployment, skills, R&D activity, industry activity, and access to finance.[26] According to the report, India ranked 43, outperforming its estimated rank of 108.

India's focus on innovation and providing Digital Public Goods (DPGs) has ensured that it stays ahead of its peers in frontier technology. India has been one of the pioneers in the development of technology stack for providing DPGs to its people. Unified Payments Interface (UPI), Digi Locker, Digi Yatra, and Open Network for Digital Commerce are some examples of DPGs pioneered in India. The lives of rural Indian citizens, 64% of the country's population,[27] have been transformed by India Stack in several ways. Convenient digital payments for goods, services, agricultural produce, etc., fosters financial inclusion and empowerment. At the same time, data storage services, like DigiLocker enable the security of important documents and certificates, and are especially helpful in accessing land records, educational certificates, or other critical documents.

Image 1: Digilocker document digitalisation solution *(Source: Digilocker website)*

The government is now providing impetus to critical frontier research through missions. One of such missions is the National Quantum Mission, aimed at promoting computing, communications, sensing, materials and devices in quantum technology. The mission focuses on scaling quantum computers, having satellite based secure quantum communications and developing quantum materials, thereby pushing new frontiers of research in quantum technologies.

In technology, the government is undertaking policy measures to ensure the development of the geospatial sector by liberalising the acquisition and production of geospatial data. Another example of using frontier technologies for pioneering use is the Svamitva Yojana run by the Ministry of Panchayati Raj, which utilises drones and Geographic Information System (GIS) technologies to provide digital land and population records. This reduces land-related disputes, enables land monetisation, and empowers the average citizen through the availability of land related information.

Similarly, National Supercomputing Mission was initiated to propel India's supercomputing abilities. In order to provide holistic support to the research community, this mission focuses on four pillars: Infrastructure, Applications, R&D and Human Resource Development. In advance materials and manufacturing, targeted policies and initiatives for Li-ion battery, Supercapacitors, Additive Manufacturing, Advanced Coatings, Fuel Cells, Rare Earth Magnets, Advanced Ballistic Materials and Glass & Ceramics are being undertaken.

In one of the major pushes towards frontier research, Laser Interferometer Gravitational-Wave Observatory India (LIGO) was given approval in April 2023 by the Union Cabinet, at an estimated cost of INR 2600 crores. The detector is expected to be operational by 2030 and is a collaboration between the National Science Foundation in the US and the DAE and the Department of Science and Technology (DST) in India.

UPI - A Global Example of financial inclusion using technology

Image 2: UPI payments *(Source: NPCI Twitter)*

"It (i.e. UPI) is an excellent example of technology boosting financial inclusion. Last month, this layer of India's digital public infrastructure processed over 8 billion transactions. The system allows 400 million people in rural areas to participate with legacy 'push-button' cell phones"

Kristalina Georgieva
Managing Director, IMF[28]

UPI was launched in India in 2016. Developed by the National Payments Corporation of India (NPCI), the real-time payment interface has been adopted by millions of people, rich and poor, urban and rural to facilitate instant digital transfer of money. As of March 2023, the UPI had recorded 8,600 million transactions of over INR 14 lakh crores in value by integrating banks, third-party payment service providers and digital wallets.[29]

A simple, straightforward use case for consumers - generate one unique ID and choose from multiple easy-to-use applications for UPI access, and the low cost for such usage has led to increased adoption and high usage of the facility. However, in addition to the nature of the UPI itself, the government's push in enabling digital and financial literacy, expansion of banking services and adoption of phones with good quality internet have all been instrumental in the success of UPI. Please refer to Section 4.1 for more details on UPI and the digital public infrastructure that has made this achievement possible.

3. Citizen Impact

Science and scientific advancements have a profound impact on the lives of citizens through improvements and advancements in healthcare, agriculture, nutrition, public service delivery etc.

In healthcare, for instance, the development of vaccines has led to the eradication of diseases such as smallpox and more recently, the near-eradication of polio. Digital expertise within the country also led to the development of COVID-19 Vaccine Intelligence Network (CoWIN), which is instrumental in maintaining digital records for vaccinations for a population of over one billion people. Under the National Mission on Interdisciplinary Cyber-Physical Systems (NM-ICPS), innovations such as the AI-driven XraySetu platform useful for Chest X-ray interpretation and rapid screening of COVID-19 patients were developed during the pandemic.[30]

Image 3: Partnerships for COVID-19 research and technology solutions *(Source: OPSA Website)*

In addition to healthcare, India has grown leaps and bounds in the availability of low-cost, high-quality digital services. The introduction of 4G and 5G services in India has led to exponential growth in the number of mobile users and businesses in India. India is experiencing massive network deployments, making it the fastest-growing 5G market globally.[31] 5G is a critical component in India's journey to realise its "Digital India" vision and can help citizens in easier, faster and predictable high-speed internet that is useful both as a consumer and provider of services.

Science and technology developments in agriculture and allied sectors are helping Indian citizens in achieving self-sufficiency and food security. In addition, newer technologies such as geospatial technology is being used to facilitate speedier planting, customised crops and harvesting. Modern agriculture practice involves geospatial technologies, such as Geographic Information System (GIS), remote sensing, Global Positioning Systems (GPS), etc. to improve production and profitability.

Another government intervention with a large impact on citizens' lives is the Startup India initiative. Whether one orders food from their favourite restaurants or buys niche products, finds cabs in a new city or finds new doctors, almost every aspect of our lives has been touched by startups in recent years. This is boosting India's position as a global creator of jobs than seekers. For instance, with the Startup India initiative, the gig workforce is expected to expand to 2.35 crores (23.5 million) workers by 2029-30, i.e., 6.7% of the non-agricultural workforce or 4.1% of the total livelihood in India by 2029-30.[32]

Technological solutions for reducing the adverse impact of climate change, waste management and urban transportation have been prioritised by the government in this decade. For instance, at Conference of Parties (COP-21) in Paris in 2015, India committed to a 40% share of power generation from non-fossil fuel sources and ended up achieving this target a decade ahead of the 2030 timeline.[33] In COP-26 at Glasgow, India committed to a Net Zero future by 2070 and established ambitious targets for sustainability, which will undoubtedly spur further innovation and research in the country.[34]

Introducing a groundbreaking shift in passenger rolling stock, India's first domestically manufactured semi-high-speed train, the "Vande Bharat" Express, was launched in 2019-20 between New Delhi-Varanasi and New Delhi-Shri Mata Vaishno Devi Katra. Since then, these trains have expanded their reach to 24 states and nearly 200 districts, covering over 12,000 kilometers. In the subsequent years (2022-23), an upgraded version, Vande Bharat trains (Version 2), was introduced and Forty-Five rakes have been manufactured indigenously till November 2023. This improved iteration boasts distinctive features, including the indigenous Automatic Train Protection (ATP) system called Kavach, emergency disaster lights, Coach Condition Monitoring System (CCMS), GPS-based public announcement, and Passenger Information System. Looking ahead, the Indian Railways envisions producing approximately 5,000 Vande Bharat Train-set coaches by 2027. Through a steadfast commitment to safety, speed, and reliability, Vande Bharat Trains are poised to revolutionise the travel experience for individuals across diverse demographics, thus elevating the standards of public service delivery.

4. National Priorities

India's national priorities for science and technology are closely tied to its public service commitments. The draft Science, Technology, and Innovation Policy of 2020 (STIP 2020) identifies agriculture and animal husbandry, water, education, biotech, pharma and health, biodiversity, climate change and environment, and manufacturing and small-level startups as key areas of national interest.[35]

In addition, exploratory scientific research initiatives like the Deep Ocean Mission and Space Exploration programs are crucial for providing India with strategic and tactical advantages for economic growth. The Indian Space Research Organisation (ISRO) has successfully undertaken missions to launch satellites, explore the moon and conduct missions that enhance the understanding of space globally. Government departments such as the DST, DAE and Department of Biotechnology (DBT) promote research on genomics, bioinformatics, pharmaceuticals, nuclear science and medical devices to fulfil the healthcare, agriculture and related requirements of the nation. The draft STIP, 2020 also emphasises the importance of promoting traditional knowledge systems, developing indigenous technologies and encouraging grassroot innovation.[36]

The Indian defence sector has made remarkable advances in R&D capabilities over the past decade. One of the notable achievements in the sector has been the successful demonstration of the anti-satellite (ASAT) missile on 27th March 2019, which highlighted India's ability to shoot down adversarial objects in space.[37] Similarly, DRDO successfully demonstrated the capability of a hypersonic cruise vehicle in 2020 which showed sustained hypersonic combustion and the attainment of cruise vehicle velocity of six times the speed of sound i.e., nearly 02 km/second for more than 20 seconds.[38] The D4 System, with capabilities of real-time search, detection, tracking and neutralisation of drones was deployed at the Republic Day Parade and Beating Retreat ceremony on Independence Day and exhibited at the Defence Expo in 2022.

India needs a separate dedicated report to explore the socio-economic impacts of defence-related technologies and innovations. This report, however, does not delve deeper into the groundbreaking achievements of the defence sector of the past decade.

The DAE has empowered the nation through advanced technologies such as accelerators, lasers, supercomputers, advanced materials, radiation technologies, nuclear medicine, and nuclear agriculture apart from building nuclear reactors for clean energy.[39]

Democratising science through encouraging 'Open Science' is one of the immediate national priorities for the government With the One Nation, One Subscription (ONOS) negotiations with journal publication houses underway, the country is simultaneously moving towards promoting Indian journals, encouraging open access to science, along with open educational resources.[40] Further, ANRF is aimed to improve the quality of research, while achieving decentralisation of its practice within the country.

The roots of the current S&T achievements of India lie in the systematic promotion of capability in the sector undertaken through governance, regulatory and financial incentives. With a multi-faceted approach of the GoI towards S&T advancements, India is blazing ahead, surpassing India's contemporaries.

The case studies covered in Part 2 of this report will include a variety of scientific interventions made in the country over the past decade, with aspects of citizen impact, systemic capability building, national priorities, and frontier technologies and research.

5. Conclusion

Given the above, it can be said that the S&T advancements in India over the past decade have laid the foundations for the country's progress and development for the future. With a focus on ensuring the ease of doing science and at the same time enabling access to technology, India is seeing remarkable growth in its scientific capabilities and achievements. The government's unwavering commitment to developing self-reliance and promoting research relevant to societal needs has been instrumental in fostering a thriving scientific ecosystem. As we look back at the achievements of the past, we must also set our sights on the path ahead, envisioning a future where India continues to lead in the global scientific landscape.

The role of the government in systemic capability building is perhaps the most important to have a long term, sustainable change in promoting S&T research. One of the key initiatives being the passage of ANRF Act, 2023, which is envisaged to help bridge the gap between the research community, educational institutions, government funding agencies as well as the industry. This will enable boosting of corporate funding for R&D in India which has traditionally been lesser than the government funding. The overall objective of the ANRF is to democratise research as well as the outcomes of such research, an intervention which has the potential to bridge the gap between research outputs and the society. Some efforts in this direction are already underway such as promotion of open science through multiple interventions, including the ONOS and promotion of indigenous scientific journals. With ANRF, these efforts will be unified and have an exponential impact on improving the current research ecosystem.

Frontier technologies and research has also been a major focus wherein India is outperforming its peers. Innovations like the UPI have transformed the lives of citizens, enabling financial inclusion and digital empowerment. Further, innovations in agriculture, healthcare, and sustainability have had a profound impact on the lives of people, ensuring self-sufficiency and progress in critical sectors. For example, the Purple Revolution caused by commercial growth of Lavender crops in the temperate regions of Jammu had a strong research backing.

Similarly, the Svamitva Yojana utilises drones and GIS technologies to provide digital land and population records, thereby empowering citizens through the availability of land-related information. Moving forward, India should continue enhancing its focus on sustainability and green technologies. By leading the way in clean and renewable energy, waste management, and climate-friendly practices, India can make significant contributions to global efforts in combating climate change and ensuring a sustainable future for the planet.

The government's emphasis on national priorities has led to strategic advances in defence, space exploration, and nuclear technology. These efforts have provided India with strategic advantages and strengthened its position in the global arena. Moreover, initiatives like the Deep Ocean Mission and Space Exploration programs have opened new frontiers for economic growth and exploration.

Overall, India's advancements in S&T have had a significant impact on improving the quality of life for its citizens, driving economic growth, and positioning the country as a global leader in scientific research. The systemic approach to capability building, focus on frontier research, national priorities, and citizen impact has been the cornerstone of this progress. However, continued efforts to promote R&D, foster collaborations, and focus on emerging technologies will be critical to sustaining this momentum and achieving even greater heights in the future. With the right policies and participation of stakeholders, India can further accelerate its growth and establish itself as a global powerhouse in the field of S&T.

S&T Case Studies

CAPABILITY BUILDING

- Start up and Innovation
  - InSPACE
  - iDEX
  - Drone
- Weather and natural disaster forecasting
- National Quantum Mission
- National Supercomputing Mission
- National Geospatial Policy
- Artificial Intelligence
- National Mission on Interdisciplinary Cyber Physical System
- Advanced materials and manufacturing
- Indigenously Developed Air Defence Systems

ENERGY

- National Green Hydrogen Mission
- National Bioenergy Programme
- National Coal Gasification Mission
- Ultra Mega Solar Power Projects
- India's Nuclear Power Program: From Science to Self-Reliance

EXPLORATION

- National Mission for Deep Ocean Exploration
- LIGO India Mission

PUBLIC SERVICE

- Digital transformation
- Communications
  - 4G
  - 5G
  - National Broadband Mission
- PM Gati Shakti National Master Plan
- Waste to Wealth

AGRICULTURE, LIVESTOCK AND BIOTECHNOLOGY

- Agriculture and biotechnological achievements
- National Digital Livestock Mission
- AROMA Mission

HEALTH

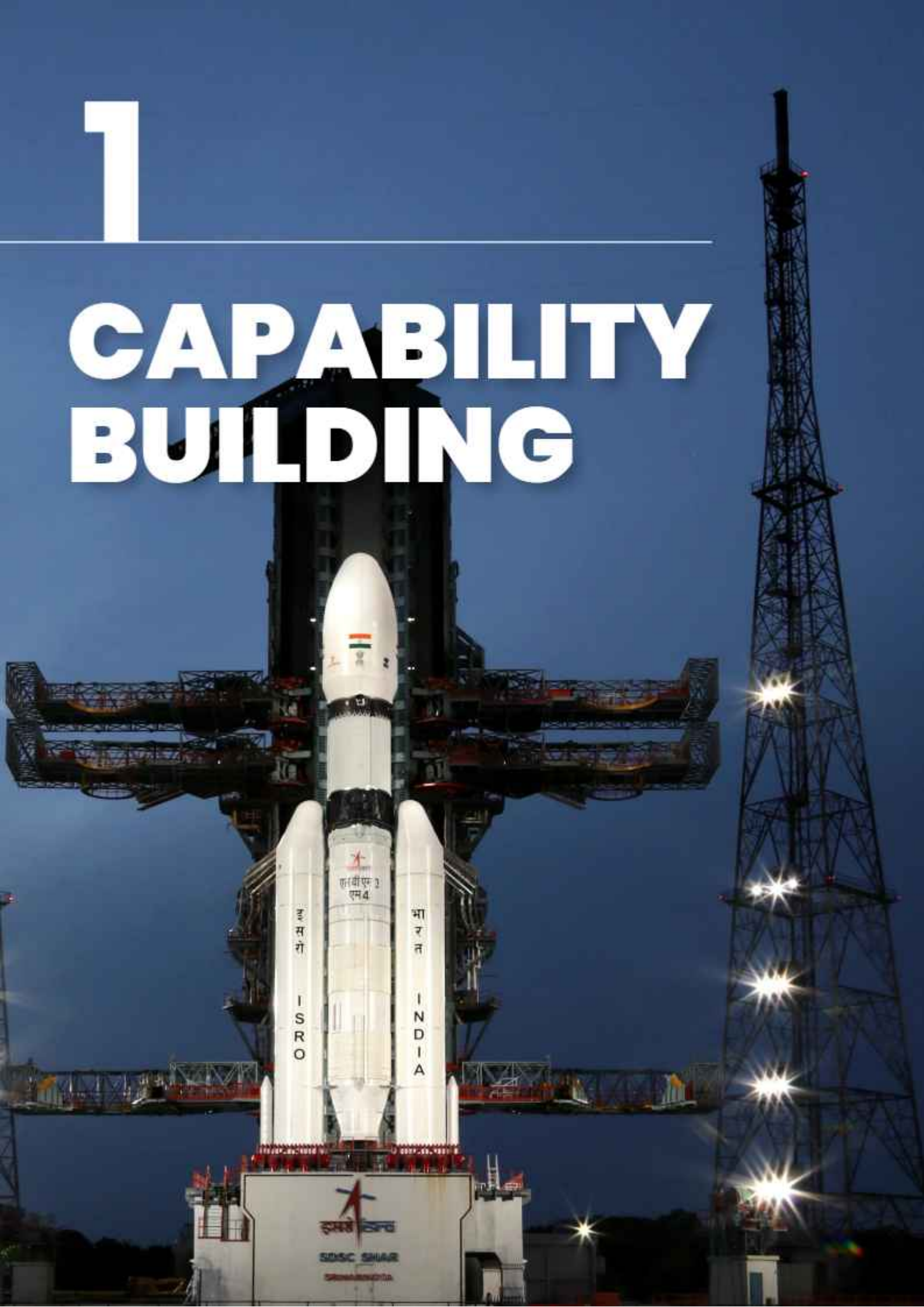
- Vaccines

PART 2

Compendium of Science and Technology Achievements in India

1

CAPABILITY BUILDING



Investing in S&T allows nations, institutions, and people to attain sustainable and long-term growth. The government plays a crucial role in systemic capability building for S&T advancements. To this end, the government has launched various initiatives and programs to support and nurture the ecosystem for S&T advancements, some of which are discussed in this section.

Perhaps one of the most important interventions in capability building by the Indian government has been the introduction of the Startup India initiative. The Startup initiative promotes entrepreneurship and innovation by providing financial support, mentorship, and networking opportunities to startups, specifically those in the S&T domain.

Indian National Space Promotion and Authorisation Center (InSPACE) the nodal agency for space activities by non-government entities which is a first of its kind venture to allow private participation within the space sector. On the other hand, Innovations for Defence Excellence (iDEX) is a program that promotes innovation and technology development in the defence sector. It provides financial support, mentorship, and opportunities for startups and individuals to develop innovative solutions for defence and security challenges.

In the realm of defence, the GoI has taken an ecosystem approach to enhancing capability of government agencies, private and public sector industry for designing and production of indigenously developed defence weapons systems, reducing our dependence on imports to safeguard the nation's security.

Drones are valuable for various applications such as surveillance, disaster management, agriculture, and logistics. In the drone technology field, the government has formulated policies and regulations to govern their operation and has established platforms for R&D to enhance their capabilities.

The government also recognises the importance of weather and natural disaster forecasting for the safety and well-being of its citizens. It has implemented initiatives to enhance meteorological capabilities and disaster management systems. Similarly, the National Quantum Mission is an ambitious initiative aimed at developing and harnessing quantum technologies. It focuses on R&D in quantum computing, communication, and sensing.

The National Supercomputing Mission aims to establish a robust supercomputing infrastructure in India. It involves the deployment of high-performance computing systems across the country and the development of indigenous supercomputing technologies, while the National Geospatial Policy (NGP) focuses on the development and utilisation of geospatial data and technologies for various applications.

Artificial Intelligence (AI) is a rapidly evolving field, and the government recognises its transformative potential. It has launched initiatives to promote AI research and development, foster collaborations between academia and industry, and create a skilled AI workforce. These initiatives aim to leverage AI technologies in various sectors such as healthcare, agriculture, transportation, and governance to enhance efficiency, accuracy, and decision-making capabilities.

The National Mission on Interdisciplinary Cyber-Physical Systems (NM-ICPS) aims to integrate various technologies such as AI, robotics, Internet of Things (IoT), and automation to create intelligent and interconnected systems. Lastly, the government recognises the importance of advanced materials and manufacturing for driving technological advancements and economic growth.

There are many ways in which India is seeking to develop its capabilities in science and technology. These include, enhancing institutional capacities, encouraging public private partnerships, identifying and promoting key areas of research and development and recognising innovation as the way of life. Investing in systemic capability building will thrust India into becoming a global superpower in coming decades.

1.1 Startup and Innovation

India's emergence as a global startup centre has been one of our standout successes in the last decade. Whether it be how we buy groceries or get milk delivered to our homes, order from our favourite restaurants to buy niche products, find cabs in a new city or find new doctors, almost every aspect of our lives has been touched by startups in recent years. Recently, India's space journey got a boost[41] to a higher orbit by startups.

Startups are not just new companies or small companies. They are, in essence, experiments to identify new markets, new technologies or products, or a new way to address a consumer's unstated need. They represent the aspiration and ambition of youth, and the freedom to find a way where none exists.

To foster entrepreneurship and promote innovation, the Hon'ble Prime Minister of India announced the launch of the "Startup India" initiative on 15th August 2015. For India to become a nation of job creators and not job seekers, the government is focussing on startups as the driving force for Indian economic growth. Startup India is a flagship initiative of the GoI, intended to catalyse startup culture and build a strong and inclusive ecosystem for innovation and entrepreneurship in India. The government provides sector-agnostic schemes, programs, and overall support to startups through incentives such as tax benefits, easier compliance, and intellectual property rights facilitation[42].

The Startup India initiative has seen phenomenal growth since 2016. As shown in the Figure 4 below, till 23rd March 2023, a total of 95,726 startups have been recognised by the Department for Promotion of Industry and Internal Trade (DPIIT) across 57 sectors and 669 districts.

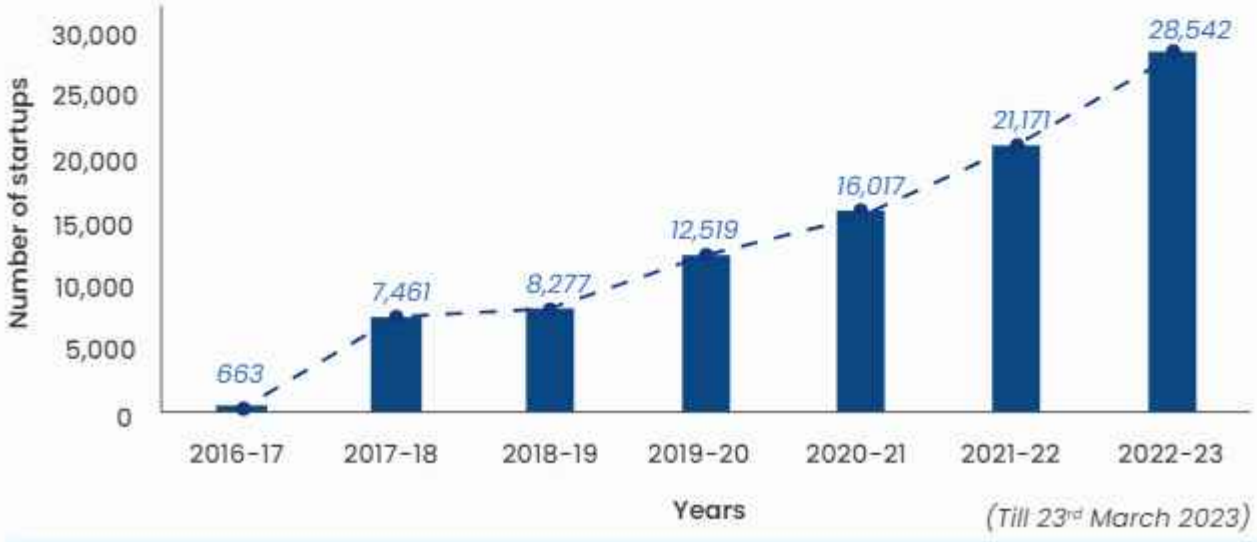


Figure 4: Growth of Startups on a year on year basis *(Source: DPIIT inputs)*

These recognised startups have reported the creation of over 10.10 lakh jobs, with an average of 11 jobs created per startup. 48% of startups registered with DPIIT are from Tier II & III cities, representing the diversity of India's ambitions. Of the recognised startups, 12% are from IT services, 9% from healthcare and life sciences, 6% from education, 5% from agriculture, and 5% are from professional and commercial services.

BIRAC - Empowering and strengthening biotechnology innovation and entrepreneurs

In its first decade of existence, Biotechnology Industry Research Assistance Council (BIRAC) has been instrumental in empowering biotechnological innovation in India. It provides funding support for ideation to proof of concept through schemes, setting up bio-incubation centers, equity funding to early-stage startups, networking, mentorship, and showcasing.

10 YEARS OF BIRAC: Nurturing & Strengthening Biotech Innovation Enterprise

75 Incubation Centres	**800+** Products in market	**4000+** Startups/other beneficiaries supported	**350+** Academia supported	**6300+ Cr** Total Investment
30,000+ High skilled jobs created	**1300+** IP filed	**4000+ Cr** Follow-on-funding raised by > 130 startups	**70,000+ Cr** Startup Valuation	**3900+ Cr** BIRAC Funding
10 Lakh+ Students/ enterpreneurs engaged	**25,000+** Proposals assessed	**100+** National & International Partnerships	**10,000+** Mentor Pool	**2400+ Cr** Co-funding by industry & Others

Image 4: Achievements of BIRAC *(Source: BIRAC website)*

Key achievements of BIRAC

FUNDING SUPPORT:

- Biotech Ignition Grant has supported over 850 innovative ideas by entrepreneurs and startups.
- Students Innovations For Advancement Of Research Explorations - Gandhian Young Technological Innovation (SITARE-GYTI) has supported 85+ scholars, and Biotech Innovation Ignition School (BIIS) workshops have trained over 600 students across 26 states and 90+ districts.
- Empowering Youth For Undertaking Value-Added Innovative Translational Research (EYUVA) has supported over 250 student entrepreneurs (UG and above).

INCUBATION CENTERS:

- BIRAC has set up 75 Bio-incubation Centers across 21 States/UT, supporting 1,800+ incubatees.
- More than 800 products developed by incubatees are in the market.

EQUITY SUPPORT PROGRAMS:

- About 150 startups have been supported through equity funding.
- 60-70% of these startups have generated INR 545 crores (10x) follow-on funding at a valuation of INR 3,065 crores.
- Over 50 products from supported startups have reached the market.

BIOTECH STARTUP EXPO AND STARTUP CONCLAVE:

- The first-of-its-kind Biotech Startup Expo featuring 300 startups and enablers was inaugurated by the Hon'ble Prime Minister.
- Startup Conclave was introduced as a sub-event under the India International Science Festival 2022.

BIOTECH SHOWCASE E-PORTAL:

- A portal featuring over 750 innovative products and technologies from BIRAC-supported startups is available at www.biotechinnovations.com

Table 1: Key Initiatives, Policies and Reforms under Startup India

Initiative	Description
Startup India Seed Fund Scheme	• Financial Outlay - INR 945 crores • Financial assistance to startups for proof of concept, prototype development, product trials, market-entry, and commercialisation • The Seed Fund is disbursed to eligible startups through eligible incubators across India.
Fund of Funds for Startups	• Corpus fund of INR 10,000 crores fund managed by Small Industries Development Bank of India (SIDBI) • The government participates in the capital of Securities and Exchange Board of India (SEBI) registered Venture Funds, which invest twice the amount in startups.

Initiative	Description
Intellectual Property Rights (IPR) benefits	• Fast-tracking of startup patent applications • A panel of facilitators to assist in IP applications • Rebate on the application filing fees.
Relaxation in public procurements norms	• Exemption on Prior Turnover, Prior Experience and Earnest Money Deposit • DPIIT recognized that startups can get listed as sellers on the GoI's largest eprocurement portal i.e. Government e-Marketplace (GeM).
Faster exit for Startups	• Startups may wind up operations within 90 days vis-a-vis 180 days for other companies.
Self-certification under Labour & Environment laws	• Allowed to self-certify their compliance under 9 Labour and 3 Environment laws for a period of 3 to 5 years from the date of incorporation.
Tax exemption and credit guarantee schemes	• The recognised startups that are granted an Inter-Ministerial Board Certificate are exempted from Income Tax for a period of 3 consecutive years out of 10 years since incorporation • A DPIIT-recognised startup is eligible for exemption from the provisions of section 56(2)(viib) of the Income Tax Act 1961, thereby being exempted from taxes on investments above fair market value.
Mentorship and capacity building	• Startup India organised a series of startup workshops Accelerating Startup Calibre & Entrepreneurial Drive (ASCEND) for existing entrepreneurs, aspiring entrepreneurs, and students from the Northeastern region • The Mentorship, Advisory, Assistance, Resilience, and Growth (MAARG) program is developed with the idea to be accessible from every corner of the country to request and connect with a mentor.

In addition to the DPIIT, other institutions such as BIRAC and The Council of Scientific and Industrial Research (CSIR) have taken several actions to promote innovation, entrepreneurship, and technology commercialisation.

NITI Aayog | ATAL INNOVATION MISSION | G20 भारत 2023 INDIA

Atal Innovation Mission

The Atal Innovation Mission (AIM) is a flagship initiative set up by the National Institution for Transforming India (NITI Aayog) in 2016 to promote innovation and entrepreneurship across the country.

AIM focuses on creating and promoting an ecosystem of innovation and entrepreneurship across the country at school, university, research institutions, and industry levels. The two core functions of the AIM include providing support and mentorship to entrepreneurs and provide a platform for innovative ideas.

AIM has implemented multiple programs to foster and support innovation in the country such as:

Atal Tinkering Labs (ATL): AIM has set up state-of-the-art ATLs in schools across the country to promote a creative and innovative mindset among students. These labs provide DIY kits on latest technologies like 3D printers, robotics, and IoT to enable students from Grade VI to Grade XII to tinker and create innovative solutions.

Atal Incubators (AICs): AIM is establishing world-class AICs at universities, nongovernmental organizations (NGOs), small and medium-sized enterprises (SMEs), and corporate industries to support sustainable startups in various sectors. The program aims to promote entrepreneurship and job creation, both in commercial and social sectors.

Atal Community Innovation Centres (ACICs): To extend the benefits of technology-led innovation to underserved regions, AIM is setting up ACICs in Tier II, Tier III cities, aspirational districts, tribal, hilly, and coastal areas. The program operates through a partnership-driven model, where AIM grants funding subject to matching funding from partners.

Atal New India Challenges and Atal Grand Challenges: AIM is launching challenges in specific areas of national importance, encouraging technology-driven innovations and product creation. Successful applicants receive grants for their innovative solutions.

Mentor of Change: AIM is promoting active collaboration between government, academia, industry, and global entities through mentorship programs. The Mentor India network connects industry professionals with students at ATLs and AIC incubators/startups.

Atmanirbhar Bharat ARISE-ANIC: This national initiative aims to promote research, innovation, and competitiveness among Indian startups and MSMEs. AIM collaborates with ministries and industries to catalyse research and innovative solutions to sectoral problems.

One of the lead authors of this report, Mudit Narain, was part of the AIM founding team in 2016-17. He had no functional or operational role with AIM at the time of drafting of this report.

Various arms of the government have joined hands to deliver on national priorities, such as the Startup India Mission.

For example, CSIR promotes the productisation of innovative projects in CSIR laboratories. The Atal Incubation Centre established with CSIR-Centre for Cellular and Molecular Biology (CCMB) nurtures early-stage innovators and startups in the life sciences and healthcare domains. Over the years, it has supported more than 90 startups through various incubation programs, funding, and acceleration initiatives. These startups have raised funds exceeding INR 200 crores, filed 30 patents, and created employment opportunities.

Venture Center, a science and technology-based business incubator under CSIR-National Chemical Laboratory (NCL) supports IP-rich startups across sectors and has incubated over 70 resident startups, with a total of more than 700 knowledge-intensive enterprises and innovators benefiting from its programs. Venture Center has filed numerous patents and trademarks, secured substantial funding, and generated significant revenue. It has become a role model for science-based incubators in the country. Working with AIM, it developed a handbook called AIM-Prime to support scientists to bring their technologies to the market, through user-informed design principles. This collaboration will allow more Indian science entrepreneurs to develop products to improve the lives of Indian citizens and strengthen the Indian economy.

Many other such cross-ministerial collaborations are starting to yield results in the innovation and entrepreneurship space.

The road ahead

The Government aims to expand the footprint of the flagship Startup India initiative by building on its success through the following mechanisms:

- **Startup India Investor Connect** initiative which connects startups and investors that intend to accelerate engagements across diverse sectors, functions, stages, geographies, and backgrounds. The platform uses AI based matchmaking to connect startups with investors who are a good fit for their business.
- **Startup 20** was an initiative of India's presidency of G20 in 2023 that aspires to build a global narrative for supporting startups and enabling synergies between startups, corporates, investors, innovation agencies, and other key ecosystem stakeholders. The group will work together to enable startup financing models and bring coherence and co-creation, especially for sectors of global importance.
- **Capacity building and supporting women entrepreneurs** by mentoring, training, and monitoring the progress of selected incubators, and developing frameworks to ensure that best practices are shared among the incubator ecosystems.

1.1.1

ACHIEVEMENTS IN SPACE

Characterised by a vision to use space technology for national development, ISRO was set up in the early 1960s, in the middle of the Cold War Space Race; to leave India's imprint on the Final Frontier. Over time, the world has started noticing and appreciating India's achievements in space such as the lowest-cost Mars orbiter Mangalyaan, the first probe to verify the presence of water on the Moon, the Chandrayaan-1, and the GPS enabling Polar Satellite Launch Vehicle. Among policy reforms, the creation of NewSpace India Limited (NSIL) to own operational launch vehicles and space assets, along with the IN-SPACe as the nodal agency for space activities by non-government entities is a first of-its kind venture to make the private sector a fellow traveler in this domain.

Novel interventions

Indian missions have achieved ground-breaking feats such as the Mars Orbiter Spacecraft, which successfully entered the orbit around Mars, and most recently, the Chandrayaan-3 mission to the Moon with the historic Lunar Landing at the South Pole of the Moon on 23rd August 2023. The Chandrayaan missions have been a fantastic example of the growing contributions of the private sector into space such as Godrej Aerospace playing an important role in all three missions. In the Chandrayaan-1 and Chandrayaan-2 missions, Godrej Aerospace contributed various components such as the Vikas engine, thrustors, and critical parts for remote sensing antenna and ground system antenna for Chandrayaan-1, and the L110 engine and CE20 engine for the GSLV Mk III launcher, thrusters for the Orbiter and Lander, and components for the DSN antenna for Chandrayaan-2[43]. They have continued to supply critical components to ISRO's Chandrayaan-3 mission.

Image 5: Skyroot's Vikram-1 launch from Sriharikota *(Source: ISRO twitter)*

Apart from this, the first successful flight of an indigenous Cryogenic Upper Stage, the experimental flight of the next-generation GSLV MK-III launch vehicle, and the establishment of the Navigation with Indian Constellation (NavIC) are noteworthy achievements. Notably, the record-breaking launch of 104 satellites in a single mission (PSLV C37) showcased India's growing prowess in space technology. The momentous Gaganyaan Program, approved in 2018, marks India's entry into human space exploration, intending to demonstrate its capability to undertake crewed missions to Low Earth Orbit (LEO) and safely recover the astronauts upon completion. The establishment of the Human Space Flight Centre (HSFC) further underscores India's commitment to fostering human spaceflight activities and spearheading advancements in this domain.

ISRO has also launched Aditya L1, the first Indian space mission aimed at studying the Sun with a budget of INR 378.53 crores. The mission, which launched the satellite on 2nd September 2023, will focus on understanding the dynamics of the Sun's corona and its impact on Earth's climate and weather patterns, including the origins of solar storms and phenomena like coronal mass ejections. By studying the Sun's corona, the Aditya L1 mission can enhance space weather forecasting, aid in mitigating climate change impacts, and inspire scientific curiosity and innovation.

Image 6: PSLV C56/DS-SAR Mission
(Source: ISRO Website)

In the context of an ever-expanding dynamic and inclusive market economy, India implemented crucial reforms in 2020 aimed at encouraging private sector participation and providing a predictable regulatory framework.

The formulation of the Indian Space Policy 2023 provides a comprehensive roadmap for the growth and development of the space sector. NSIL, a PSU (Public Sector Undertaking) under the Department of Space, has been empowered to own operational launch vehicles and space assets. The IN-SPACe has been set up as the nodal agency for space activities by non-government entities, to provide a level playing field for all stakeholders while also being responsible for actively supporting and promoting startups in the space domain. It facilitates infrastructural support by enabling the utilisation of capital-intensive facilities, provides intellectual support through technological mentorship from experienced ISRO experts, and offers earlystage funding through a dedicated startup seed fund. Additionally, a differential pricing policy is being developed to facilitate technology transfer and access to Earth observation data/products from ISRO for startups.

Image 7: The firing of Dhawan-1, India's first privately built fully Cryogenic Engine
(Source: Skyroot Aerospace twitter)

Apart from this, there have been advancements in launch vehicle technology, such as the successful flight of the indigenous Cryogenic Upper Stage and the experimental flight of the GSLV MK III. Establishment and Operationalisation of NavIC which provides highly accurate position, navigation, and time information to users in India and its surroundings, as well as the launch of the first dedicated Indian astronomy mission – AstroSat – launched in September 2015, aimed at studying celestial sources in X-ray, optical and UV spectral bands simultaneously.

Table 2: Key outputs

Output	Description
Space Technology for Governance and Development	National Meet In September 2015 to strengthen and expand the use of space-based technology in governance and development - included government stakeholders, including Secretaries to the GoI and state government representatives, and presented a joint Plan of Action prepared with ISRO for enhanced space technology utilisation.
Increased frequency of Space Missions	45 spacecraft missions, 43 launch vehicle missions, and 5 technology demonstrators since 2014.
Major Missions	• Successful flight with indigenous Cryogenic Upper Stage in GSLV D5 (January 2014). • Successful entry of Mars Orbiter Spacecraft in orbit around Mars (September 2014). • Experimental flight of GSLV MKIII (December 2014). • Establishment and operationalisation of Navigation with Indian Constellation (NavIC). • Launch of AstroSat, India's first dedicated astronomy mission (September 2015) • PSLV C37 launch placing 104 satellites in orbit (2017). • Chandrayaan-2 mission to the Moon (July 2019). • Launch of Vikram-1, India's first privately developed rocket by Skyroot Aerospace • Successful flight of Small Satellite Launch Vehicle (SSLV – D2) (February 2023). • The launch of PSLV-C56 carrying DS-SAR satellite (July 2023) • Successful Chandrayaan-3 mission to the moon with the first successful South Pole Lunar landing.
Reforms in the Space Sector	Creation of NSIL to own operational launch vehicles and space assets, along with IN-SPACe as the nodal agency for space activities by non-government entities.

Output	Description
Mechanisms for Promoting and Enabling Startups	Infrastructural support, intellectual support, institutional support, startup seed fund, and differential pricing policy.
Gaganyaan	Gaganyaan was approved in 2018, aiming to demonstrate human space flight capability to LEO. Successful Pad Abort Test, realisation of test launch vehicle, advanced stage of crew module realisation, and qualification tests done so far.
Increasing Private Activities in Space	Over 200 proposals received by IN-SPACe, more than 150 space startups in 2022 from 1 in 2014, increased Foreign Direct Investment (FDI) from $6 Mn in 2019 to over $111 Mn in 2022.
Capacity Build-up in Indian Industries	Hindustan Aeronautics Limited (HAL) and Larsen & Toubro (L&T) consortium for production of PSLV launch vehicles, transfer of technology to boost indigenous spacecraft development

Image 8: Launch of the LVM3-M4 / Chandrayaan-3 Mission on 14th July 2023
(Source: ISRO website)

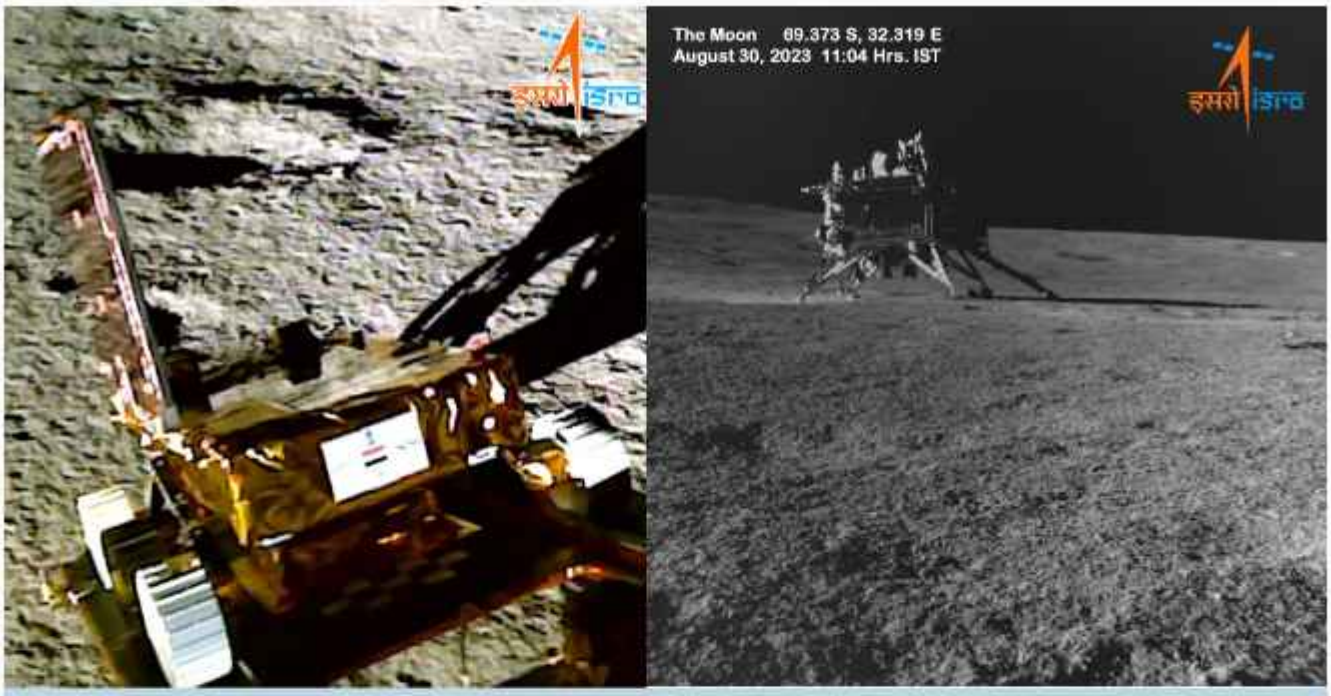


Image 9: Chandrayaan-3 rover *(Source: ISRO website)*

Chandrayaan 3: Lunar Landing by India

23rd August 2023 will forever be etched in the hearts of Indians as ISRO's Chandrayaan-3 demonstrated successful soft-landing on the moon. With this feat, India became the fourth nation to land on the moon and the first to land at the South Pole of the Moon.

After a successful soft-landing through Vikram, the landing module, the mission's lunar rover, Pragyan will navigate and conduct in-situ testing on the lunar surface. The lander and rover will study the lunar surface of the South Pole, and conduct scientific experiments in an unexplored area. As the mission continues, the data that the lander and rover will send back to us will allow us to visualise and understand a hitherto unknown territory.

The lunar landing is a tremendous achievement for India, catapulting it into an elite group of nations in space exploration. Chandrayaan-3 will forever remind our nation that we have the scientific ability, the technological know-how and the determination to push our capabilities to deliver for the nation and, indeed, the world.

Citizen Impact and National Priorities

India's journey into space over the last decade has been characterised by an unprecedented scale of development. This has been the result of funding and facilitation of R&D within the sector and has resulted in innovations with downstream benefits for India's citizens. The rapidly increasing Earth observation satellite fleet enables better monitoring and management of resources, weather forecasting, and disaster response, along with communication services across the country.

The role of the Indian Space Policy to establish a predictable and level playing field in the space sector has resulted in private players interested in building small satellites and rockets in India. Driven by lower production costs, minimal infrastructure requirements, the use of commercial-off-the-shelf components, reduced testing requirements, economies of scale, and lower launch costs, this shift has the potential to accelerate space innovation and manufacturing in India exponentially. Increasing FDI inflows enabled by Production Linked Incentives (PLIs) and technology transfer schemes within the sector already suggest a move towards India becoming a space manufacturing hub.

1.1.2

iDEX: EMPOWERING INDIGENOUS INNOVATIONS IN DEFENCE

FACTSHEET

Year of Union Cabinet Approval	2018
Financial Outlay	INR 498.80 crores from 2021-22 to 2025-26
Objective	**Indigenisation:** Accelerated development of indigenous and innovative technology. **Innovation:** Cultivate engagement with startups, MSME's, individual contributors and academia to foster co-creation.
Key Achievements	• Following on the success, iDEX-Prime launched in 2022 to support startups for projects beyond INR 1.5 crores up to INR 10 crores. • iDEX received the Prime Minister's Award for Excellence in Public Administration 2021 under the 'Innovation (General) – Central' category.
Current Status[44]	• To date, more than 7,500 applications received from individual innovators, MSMEs and startups. • More than 300 startups engaged. • Milestone 250th contract signed in May 2023. • Defence India Start-up Challenge (DISC 9) launched in March 2023.

iDEX Innovations for Defence Excellence

PM Awardee

INTRODUCTION

iDEX is a pioneering initiative launched by the GoI to foster innovation, indigenisation, and technological advancements in the defence sector. iDEX aims to harness the immense potential of startups, MSMEs research institutes, and academia to address the complex challenges faced by the defence industry.

iDEX was conceptualised with the recognition that innovation is the lifeblood of progress and transformation in any sector, especially defence. It aims to ignite innovation by creating an ecosystem that fosters collaboration, knowledge exchange, and technology transfer among diverse stakeholders. By engaging startups, MSMEs, research institutes, and academia, iDEX seeks to tap into its creative potential to develop disruptive solutions, cutting-edge technologies, and indigenous capabilities that strengthen India's defence sector.

The Catalyst

At the heart of the conceptualisation of iDEX lies the essence of Aatmanirbharta. It encapsulates a vision of diminishing reliance on foreign imports and nurturing the development of indigenous capabilities to cater to the distinctive defence requirements of the nation effectively. Aatmanirbharta in the defence sector finds its impetus in the pursuit of bolstering national security, fostering strategic autonomy, and nurturing the seeds of economic growth by

- Promoting domestic manufacturing of defence equipment to reduce reliance on
- imports. Investing in R&D to foster innovation and create cutting-edge technologies.
- Encouraging defence exports to enhance self-reliance and contribute to the economy.
- Supporting startups, MSMEs, and innovators to drive indigenisation and self-reliance through initiatives like iDEX.

Image 10: Fire Fighting Bots procured for the Indian Navy through the iDEX SPRINT initiative
(Source: iDEX Twitter)

Key government interventions[45]

The government complemented its impassioned call for self-reliance in the defence sector by enacting a series of policy reforms to liberalise the heavily regulated and monopolistic defence production market. Some of the key reforms are as under.

- **Priority to Buy Indian (IDDM) Category:** The government has prioritised the procurement of capital items from domestic sources under the Defence Acquisition Procedure (DAP)-2020, emphasising indigenous design, development, and manufacture of defence equipment.
- **Positive Indigenisation Lists:** The government has issued 'Positive Indigenisation Lists' for both Services and Defence Public Sector Undertakings (DPSUs), comprising a total of 411 items and 3,738 items, respectively. Import beyond specified timelines for these items is embargoed, encouraging domestic production.
- **Simplification of Industrial Licensing Process:** The government has simplified the industrial licensing process, providing longer validity periods and making it easier for companies to obtain licences for defence manufacturing.
- **Liberalisation of FDI Policy:** The FDI policy has been liberalised, allowing up to 74% FDI under the automatic route and encouraging foreign investment in the defence sector.
- **Simplification of Make Procedure:** The Make Procedure has been simplified to promote indigenous development and manufacturing of defence equipment, allowing more domestic industry and startup participation.
- **Mission DefSpace:** The government has launched Mission DefSpace to enhance India's capabilities in the space sector, promoting self-reliance and innovation in defence-related space technologies.
- **iDEX Scheme:** The iDEX scheme encourages startups and MSMEs to contribute their innovative ideas and technologies to address defence challenges, fostering innovation and indigenisation. Riding on the success of iDEX, the government has also launched iDEX PRIME in 2022 to support startups for projects beyond INR 1.5 crores up to INR 10 crores.
- **Public Procurement (Preference to Make in India) Order 2017:** The implementation of this order gives preference to domestic manufacturers in public procurement, promoting indigenous production and reducing dependency on imports.
- **SRIJAN Indigenization Portal:** The SRIJAN portal facilitates indigenisation by Indian industries, including MSMEs, providing a platform for collaboration, information sharing, and support for indigenous manufacturing in the defence sector.
- **Reforms in Offset Policy:** The offset policy has been reformed to attract investment and facilitate technology transfer for defence manufacturing, focusing on domestic industry development.

- **Defence Industrial Corridors:** Establishing two Defence Industrial Corridors in Uttar Pradesh and Tamil Nadu aims to create specialised ecosystems for defence manufacturing, promoting investment, innovation, and employment opportunities.

- **Allocation of R&D Budget:** The government has earmarked 25% of the R&D budget for industry-led research and development, encouraging collaboration and innovation in the defence sector.

These policy interventions exemplify the government's steadfast dedication to fostering self-reliance, indigenisation, and technological progress within the Indian defence manufacturing and technology sector. These initiatives have catalysed the remarkable achievements of the iDEX model.

The iDEX working model

iDEX engages with stakeholders in the defence sector to identify specific problem statements or challenges. These statements are released through 'Open Challenges' or 'Defence India Startup Challenges' (DISC). Startups, MSMEs, research institutes, academia, and individual innovators are invited to submit proposals addressing these problem statements.

A rigorous evaluation process conducted by domain experts and industry professionals selects the most promising proposals based on innovativeness, feasibility, technical viability, and scalability. Selected proposals receive support and funding from iDEX, including financial assistance, access to infrastructure, mentorship, and guidance for prototype development.

iDEX fosters collaboration and networking by connecting innovators with industry experts, defence organisations, potential customers, investors, and mentors. This network helps establish partnerships for enhanced viability and marketability. Successful innovators get opportunities to deploy and demonstrate their solutions within the defence establishment through pilot projects and integration into defence systems.

Continuous feedback and iteration are encouraged throughout the process, allowing innovators to refine and enhance their solutions based on specific defence requirements. iDEX supports the scale-up and commercialisation of successful innovations, assisting in securing contracts and orders from defence organisations and facilitating market access for sustained growth and impact.

Image 11: DEFCONNECT 2.0 event *(Source: iDEX website)*

Image 12: The Indian Army has signed a contract for the Tactical LAN Radio, state of the art high bandwidth backhaul wireless radio equipment for provisioning of reliable and failsafe communication, through iDEX (Source: Press Information Bureau, 9th June 2023)

Image 13: A showcase of drones developed by iDEX startups (Source: iDEX website)

Key achievements

- iDEX has been awarded the prestigious Prime Minister Award for Public Administration in Innovation Category for
- the year 2021.
  Under iDEX, 233 problems have been opened, more than 300 startups have been engaged, and 250 contracts have
- been signed to date.
  iDEX Prime framework under iDEX was launched in 2022 to support startups with Grant-in-Aid up to INR 10 crores to enable the development of high-end solutions.

Conclusion

Indigenisation of the Indian defence sector and the launch of iDEX go hand in hand. Indigenisation is the overarching objective, driven by the need for self-reliance in defence, while iDEX operationalises this vision by promoting innovation, indigenisation, and technological development through its specific programs and initiatives.

iDEX provides a structured framework and platform to tap into the immense talent and entrepreneurial spirit of the Indian innovation ecosystem. By encouraging indigenous innovation, iDEX aims to reduce dependence on foreign technology, enhance domestic manufacturing, and elevate India's position as a global leader in defence capabilities.

One of the lead authors of this report, Mudit Narain, had been engaged in the design and initiation of iDEX in 2017-18. He had no functional or operational engagement with iDEX at the time of drafting of this report.

1.1.3

INDIA'S SOARING JOURNEY IN THE DRONE SECTOR

Autonomous flying vehicles were a central portion of many science fiction books till barely a few years ago. And today, most of us have seen drones of some kind or the other or even controlled them with our own hands. The progress on drones around the world in the last few years has been astounding, and India has kept pace in most areas.

QDrones, or Unmanned Aerial Vehicles (UAVs), are aircraft that operate without a crew onboard. They can be controlled remotely or operate autonomously, relying on sensors and Light Detection and Ranging (LiDAR) detectors to navigate their flight paths.

Drones were initially confined to warfare, but since the 1980s, their applications have expanded. They are now used for intelligence gathering, surveillance, combat missions, and humanitarian purposes. In the civilian realm, drones perform tasks like building and pipeline inspections, landmine detection, agricultural and forest mapping, rescue operations, surveying, filming, and delivering essential supplies during calamities to inaccessible areas. Their versatility has revolutionised various industries and provided efficient solutions to complex challenges. Leveraging its traditional strengths in innovation, information technology, and frugal engineering, coupled with a vast domestic market, India is poised to become a global drone hub by 2030.

Table 3: Drone usage in different sectors

Sector	Usage
Agriculture	Useful for crop monitoring, precision agriculture, and yield optimisation. They provide real-time data on crop health, nutrient levels, and water requirements, enabling farmers to make informed decisions and improve productivity.
Infrastructure & Construction	Facilitate efficient surveying and mapping of construction sites, monitoring project progress, and conducting inspections of infrastructure such as bridges, buildings, and power lines. They enable accurate measurements, reduce human error, and enhance safety.
Disaster Management	Important for disaster response and recovery. They aid in search and rescue operations, deliver essential supplies to affected areas, assess damage, and provide emergency responders with situational awareness.

Sector	Usage
Logistics & Delivery	Drones are increasingly being explored for last-mile delivery in both urban and rural areas. They offer fast and cost-effective delivery of small packages, medical supplies, and emergency supplies, especially in hard-to-reach or remote locations.
Environmental Monitoring	Environmental conservation and research purposes. They help monitor wildlife populations, survey habitats, assess forest cover, and track ecosystem changes. Drones also support anti-poaching efforts and help combat illegal activities such as deforestation and wildlife trafficking.
Media & Entertainment	Drones have revolutionised the field of cinematography, providing stunning aerial footage and unique perspectives. They are employed in filmmaking, sports coverage, and event photography, enabling creative storytelling and captivating visuals.
Security & Surveillance	Drones offer enhanced capabilities for security and surveillance purposes. They are utilised in border surveillance, crowd monitoring, critical infrastructure protection, and law enforcement operations, providing real-time video feeds and intelligence gathering.
Research & Development	Drones are valuable tools in scientific research and development. They support data collection in various fields, such as atmospheric research, archaeological surveys, geological studies, and wildlife conservation, enabling researchers to access remote or hazardous areas.

Key government interventions[46]

Till the early 2010s, the use of drones in India was sporadic and unregulated, with a heavy reliance on imports and it was an unorganised industry. However, recognising the global significance of drones and their diverse applications, the current government prioritised the development of the drone industry and its potential. Embracing a self certification and trust-based approach, the government has implemented several key initiatives to foster growth and innovation in this transformative sector.

Image 14: Drone applications in the agriculture sector *(Source: Drone Federation of India inputs)*

1. Liberalised Regulatory Framework

- The Drone Rules 2021:
  One significant step was the repeal of the old drone rules and the introduction of the liberalised Drone Rules, 2021 on August 25, 2021. These rules streamlined the drone policy by reducing the number of forms from 25 to 5 and simplifying the fee structure from 72 types to 4. This liberalisation provided a boost to the industry, paving the way for smoother operations and greater accessibility.

- Aatmanirbharta through Production - Linked Incentive (PLI) scheme:
  To incentivise domestic drone manufacturing and innovation, the government introduced the PLI scheme for drones on September 30, 2021. With an allocation of INR 120 crores, this scheme offered a consistent PLI rate of 20% for three years, an exceptional treatment provided exclusively to the drone industry. This initiative aimed to encourage indigenous production and bolster the growth of the sector.

- Opening up Indian airspace
  Another crucial milestone was the publication of the drone airspace map on September 24, 2021, in collaboration with numerous entities across Union Ministries, States, and Union Territories. This map designated nearly 90% of Indian airspace as a green zone for drones flying up to 400 feet, eliminating the need for permission to operate drones within this range. Furthermore, the requirement for security clearance was abolished, facilitating a more streamlined and efficient operation of drones.

Image 15: Airspace map for Drones available on Digital Sky Plaform
(Source: Digital Sky platform on Directorate General of Civil Aviation website)

2. Establishment of guidelines and embracing digitisation

- UAS Traffic Management Policy Framework:
  To ensure efficient management of drone traffic, the UAS Traffic Management (UTM) Policy Framework was published on October 24, 2021. This framework established guidelines for the safe and seamless integration of drones into the airspace, fostering a conducive environment for their widespread use.
- Digital Sky Platform:
  The government also launched the Digital Sky Platform, making all five application forms under the Drone Rules, 2021 available online since January 26, 2022. This digital platform streamlined the application process and facilitated ease of access for drone operators.
- Ban on imports:
  On February 9, 2022, India introduced a drone import policy that prohibits the import of drones and drone kits. However, the import of components remains unrestricted, aiming to stimulate domestic intellectual property creation in the drone industry.
- Ease of obtaining licencses:
  On February 11, 2022, the Drone Amendment Rules were announced, eliminating the need for a drone pilot licence. Instead, a Remote Pilot Certificate (RPC issued by a DGCA-authorised drone school) is now sufficient for operating a drone in India.

3. Promotion of the drone sector:

- Drone melas:
  These have been organised in 12 states across the country to highlight the use cases and the policy reforms.

Image 16: Drone Outreach Program in Gujarat 2021 *(Source: Ministry of Civil Aviation website)*

- Bharat Drone Mahotsav 2022:
  An exhibition-cum-conference, took place from May 27-29, 2022 at Pragati Maidan. The event was graced by the presence of the Hon'ble Prime Minister as the Chief Guest and witnessed participation from leaders in government, armed forces, diplomatic corps, industry, start-ups, and academia. The exhibition drew over 70 drone exhibitors and welcomed 10,000 visitors.
- Stakeholder role:
  Promoting the drone ecosystem involves key institutional stakeholders such as the Ministry of Civil Aviation, Ministry of Home Affairs, Ministry of Commerce and Industry, and various state governments. Additionally, the private sector plays a vital role as a significant stakeholder, driving the proliferation of drone technology and its applications.

Key achievements[47]

- **Growth in manufacturing:** More than 80 drone manufacturing units have been established in India. The drone industry witnessed significant growth following the liberalisation of policies in 2021. Revenue soared from INR 88 crores in FY 2020-21 to INR 319 crores in FY 2021-22, marking an impressive growth rate of approximately 261%.
- **Increased interest from the private sector:** Interest from both startups and established corporates in the drone sector has been on the rise. From August 2021 to February 2022, the number of drone startups in India increased by 34.4%, reaching a total of 221.
- **Growth in Research & Development:** Drone companies have filed approximately 37 patents related to technologies like propeller safety in automated aerial vehicles since 2015.
- **Incentivisation scheme:** Under the PLI scheme for drones and drone components, manufacturers received incentives amounting to approximately 29 crores for the fiscal year 2021-2022.
- **Growth of the Drone service market:** The drone service market in India was valued at $130.4 million in 2020 and is projected to reach $4,918.9 million by 2030, with a compound annual growth rate (CAGR) of 44.4%. Specifically, the drone maintenance, repair, and overhaul (MRO) services and drone

training and education services segments are expected to grow at a CAGR of 46.8% and 45.2% respectively until 2030.

- **Wide adoption of drone technology:** Drones are being extensively adopted by both the government and private sector for various applications. These include land record creation under the Svamitva scheme, pesticide spraying, infrastructure monitoring, construction monitoring of national highways, railway track inspections, oil and gas pipeline surveillance, wildlife monitoring, and medicine and vaccine delivery. Additionally, the armed forces are procuring drones on a large scale through expedited processes.
- **Skilled workforce pipeline:** To meet the industry's demand for skilled professionals, 50 drone training schools have been established nationwide, training a total of over 3,876 drone pilots to date.

Conclusion

India's drone sector has experienced remarkable growth and achieved significant milestones over the past decade. With the liberalisation of policies, the sector witnessed a surge in drone manufacturing units, attracting both startups and established corporates. The future potential of the drone sector in India is immense. The government's initiatives, such as the liberalised Drone Rules, PLIs, and the establishment of drone training schools, have laid a strong foundation for continued growth. The sector is expected to witness further advancements, particularly in drone applications like land record creation, infrastructure monitoring, agriculture, surveillance, and healthcare.

With continued government support, technological advancements, and increasing investments, India's drone sector is poised for exponential growth. It has the potential to become a global drone hub by 2030, creating employment opportunities, driving innovation, and contributing significantly to the country's economic growth.

1.2

WEATHER AND NATURAL DISASTER FORECASTING

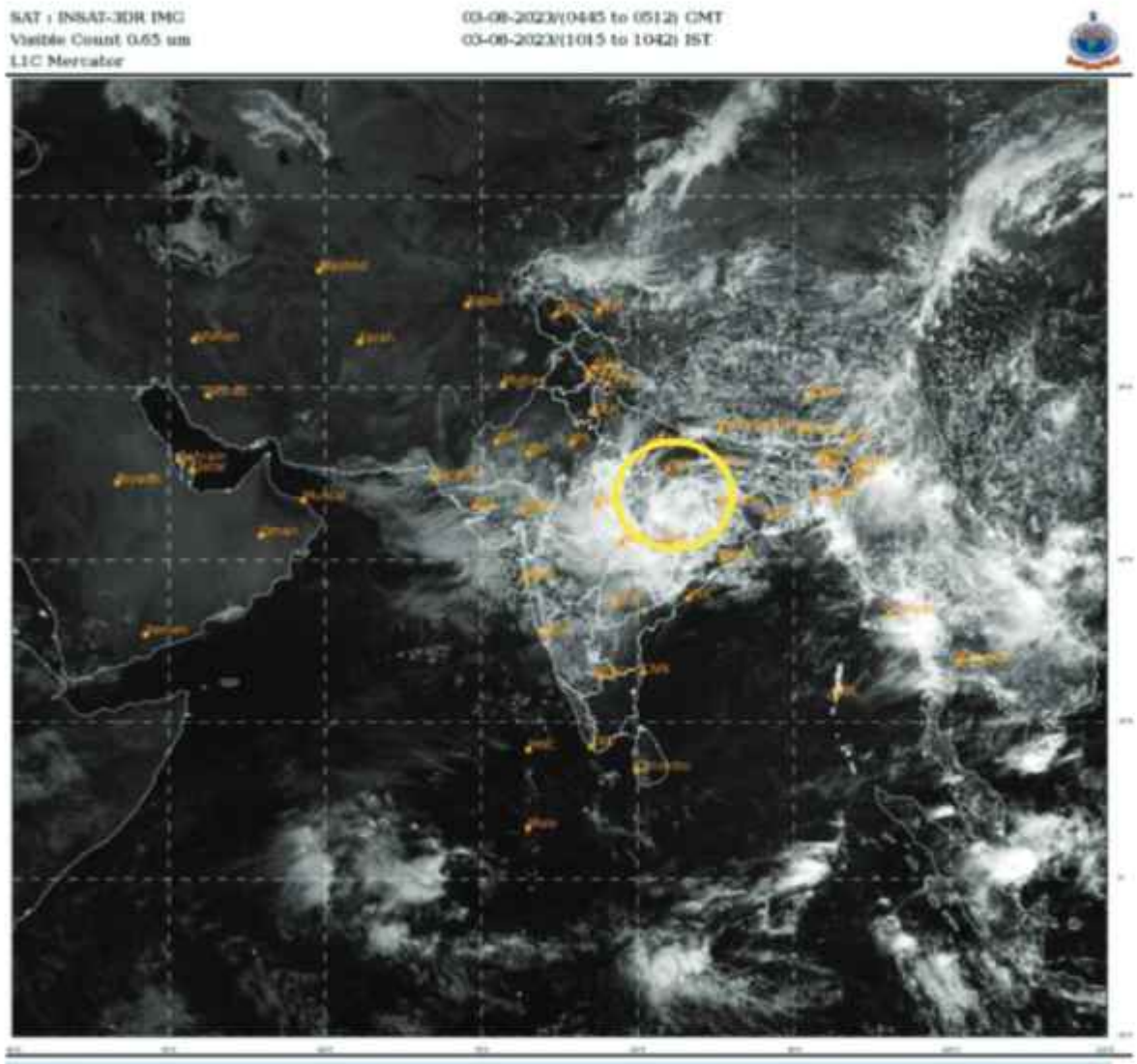


Image 17: Satellite image from National Bulletin for Cyclone Information
(Source: Indian Metreological Department website)

Extreme weather events cause cataclysmic natural disasters resulting in large-scale population migration and casualties. As climate change is expected to cause a manifold increase in the frequency of extreme weather events and natural disasters in the coming years,[48] forewarned is forearmed. Even seconds of warning before natural disasters such as earthquakes and tsunamis can be the difference in saving lives.

India is no stranger to natural disasters each year and is prone to severe weather patterns, cyclones, earthquakes, landslides, and flash floods in different parts of the country.

Forecasting the possibility and extent of many of these natural disasters has come a long way in the last several years aided by technological and scientific advancements such as new sensors, satellites, and supercomputing among others.

Weather and severe event forecasting

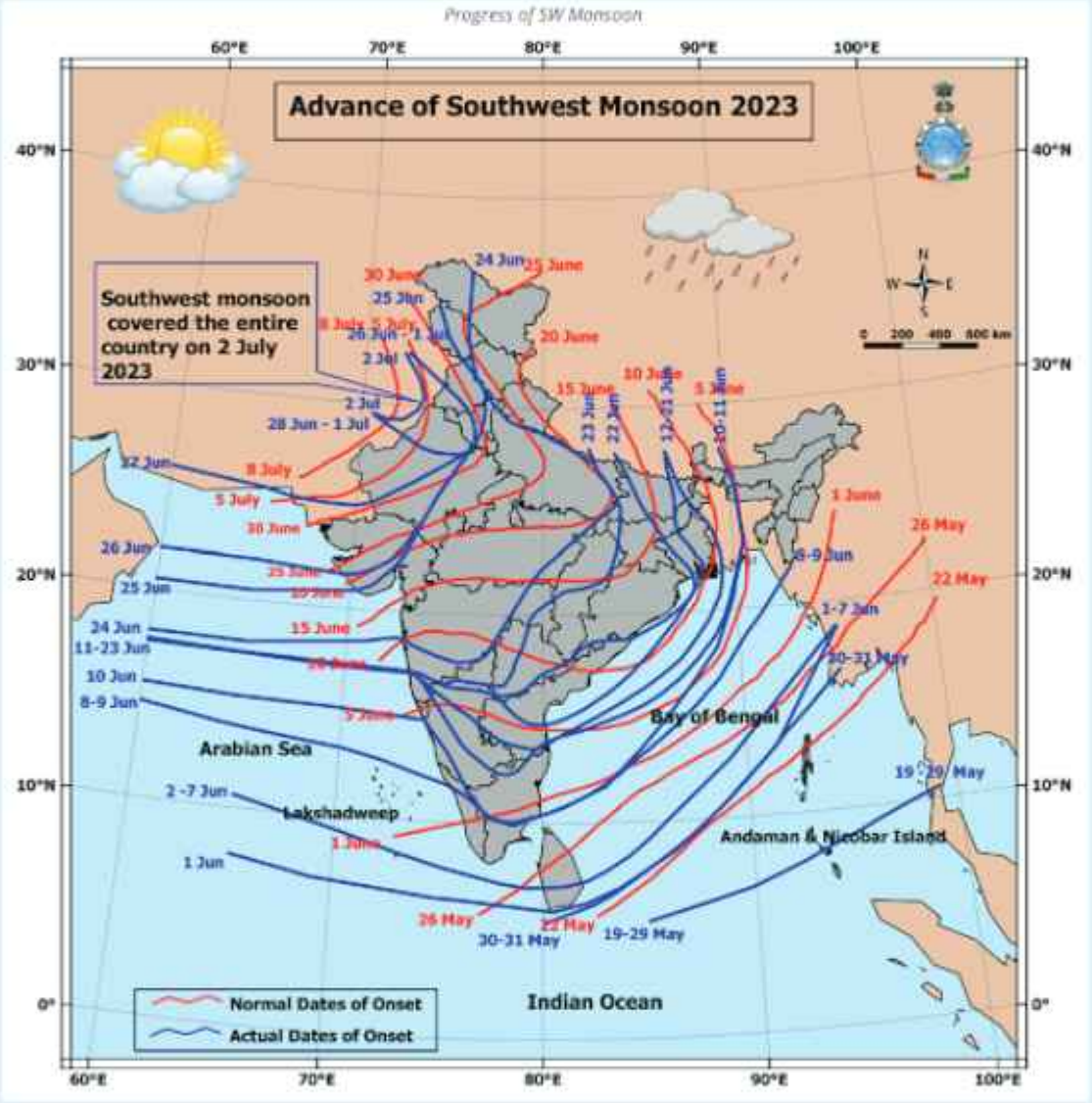


Image 18: Advancement of South-West Monsoon 2023
(Source: Press Information Bureau, Ministry of Earth Sciences, All India Weather Forecast)

The onset of the Indian monsoon is a much-celebrated event in Indian culture, dance, music, and literature. The onset of the Indian monsoon is anticipated as it provides respite to humans and nature from the heat during the summer. The national agrarian economy is highly dependent on rainwater. The country is well aware of the destructive capacity of this annual event and a severe monsoon or a lack of monsoon are equally devastating scenarios.

The Indian Monsoon is one of the most complex coupled climate systems of the world and the geographic location of India makes the system more difficult to simulate and predict.[49]

Over the last several years, the GoI has made significant investments in upgrading the technology and infrastructure to improve the weather forecasting ability of the country. From heatwaves to flooding and cyclones, the country relies on technology to makes accurate predictions.

There has been a 40-50% improvement in Severe Weather (cyclones, heavy rainfall, heat wave, cold wave, thunderstorms, fog) forecast with a lead period of five days during the last five years.[50] India is employing Pratyush and Mihir – two of the most powerful civilian supercomputers in India that are used to help model the quality of weather forecasts, including monsoons.[51] They also support the forecasting of natural disasters such as cyclones, earthquakes, and other extreme events. Pratyush is located at the Indian Institute of Tropical Meteorology (IITM) in Pune, while Mihir is housed at the National Centre for Medium-Range Weather Forecasting (NCMRWF) in Noida.[52]

An expansion of the South Asia Flash Flood Guidance System (SAFFGS) for providing flash flood guidance to Bangladesh, Bhutan, India, Nepal, and Sri Lanka. SAFFGS, having a high resolution of 4x4 km and covering 30,000 watersheds over the Indian region is capable of issuing flash flood threats and risk for the next 6 and 24 hours respectively.[53]

An Atmospheric Research Testbed[54] (ART) facility has been established in Madhya Pradesh to study important atmospheric processes particularly: clouds and convection; land-atmosphere interactions; aerosol and radiation; and thunderstorms, for developing and testing the parameterisation schemes in weather and climate models by implementing advanced measurements of clouds, radiation, precipitation, dynamics and land-surface parameters in the core monsoon zone.

A new merged rainfall product has been developed, the Multi-Ensemble Rainfall Analysis (MERA),[55] with a spatial resolution of 4 km, and a temporal resolution of 1 hour. It involves satellite rainfall products from GPM-IMERG, GSMAP, INSAT, and the Indian Radar network. A High-Resolution Global Forecast Model (HGFM),[56] in its experimental version, with a horizontal resolution of 6 km has been implemented to improve the prediction of smaller-scale weather extremes. A scientific strategy is adopted by using Triangular Cubic Octahedral (TCO) grid which is very scalable after a thorough validation and performance evaluation, the model will be handed over for operational implementation to Indian Meteorological Department.

Earthquake Early Warning System in India

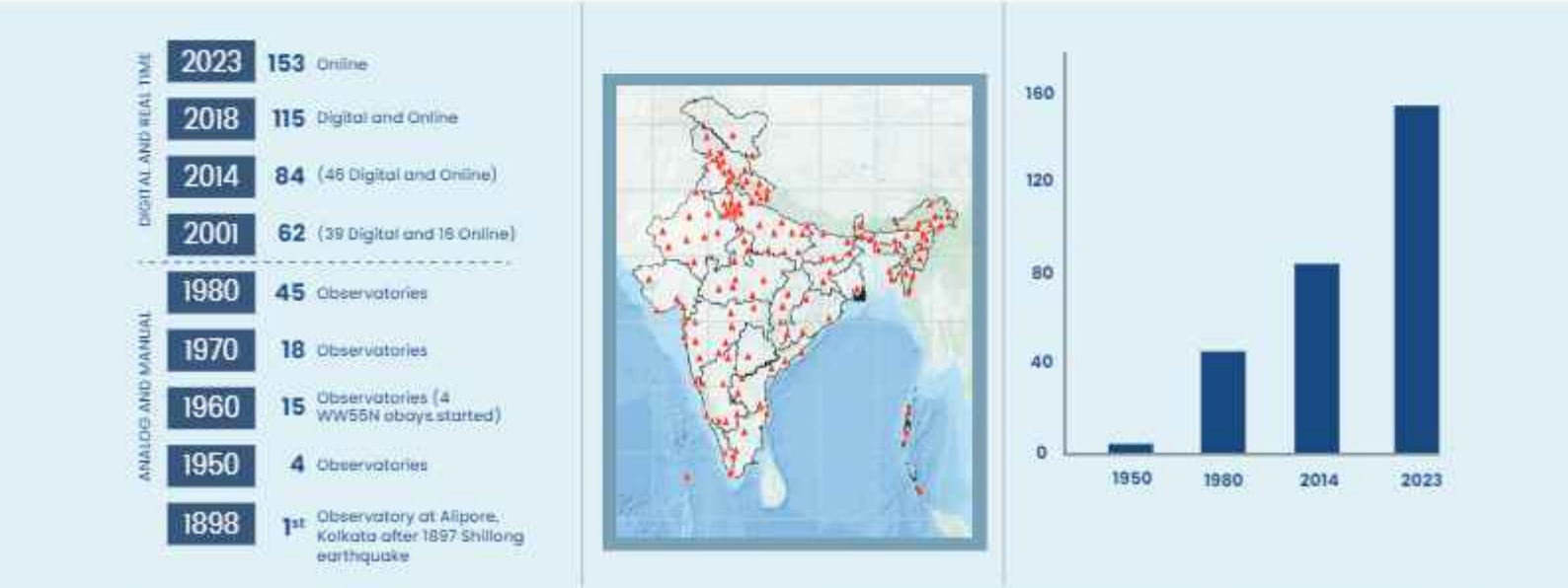


Figure 5: Growth of National Seismological Network *(Source: National Centre for Seismology website)*

India, by virtue of its geographical location, sits at the edge of a tectonic plate and has regions such as the Himalayas, that are prone to earthquakes.

There is no technology today that can accurately predict exactly where and when earthquakes will strike or how intense they will be today anywhere in the world. However, early warning systems can alert populations as to when the shaking tremors or 's waves' will arrive, based on the detection of 'p waves' that move faster through the earth's crust.

An earthquake early warning system is a network of detectors and communications systems that can detect p-waves generated by a tremor and convey the information to locations further away from the detection site, allowing some time for these areas to possibly prepare for the imminent earthquake. However, the lead time for this can be tens of seconds to seconds.

India operates and maintains the National Seismological Network (NSN).[57] NSN consists of 153 seismological observatories spread across the country and maintains a round-the-clock watch of seismic activity in the country. A Central Receiving Station (CRS) at NCS receives real-time digital waveform data from field stations. This data is used to determine preliminary earthquake source parameters. NCS shares information about earthquakes via earthquake bulletins within five minutes of an event. It is also involved in the monitoring of aftershocks and swarm activity throughout the country. The aim is to add 35 more seismic stations in the next 1-2 years, and nearly 300 seismic stations in the next five or so years. This will increase the capability of detecting earthquakes of upto magnitude 2.5 or M 2.5 throughout the country and will enhance location capabilities for earthquake mitigation.

There are also R&D activities on various aspects of seismology and earthquake engineering, such as delineation of geological structures, monitoring of local faults, study of slow earthquakes, rupture propagation, attenuation studies, site characterisation, simulation of ground motion and liquefaction investigations carried out by individual researchers in project mode in selected areas.[58] These studies have helped understand seismogenesis, and seismotectonics, and conduct an assessment of seismic hazards and the design of structures. In addition, over 60 GPS and 50 broadband seismometers, have been established in project mode in the country with specific objectives.

Recognising the importance of active tectonics, a dedicated program was initiated to undertake active fault mapping of the country systematically and comprehensively.[59] This program aims at defining and categorising the active faults of India, generating composite datasets and ensuring their availability to the users in a GIS-compatible format and preparing active fault maps of different regions and the country. Four areas, North-West and Central Himalaya, Kashmir Himalaya, North-East Himalaya, and Kachchh have been selected as priority areas. An initial document for active fault mapping has been prepared, which provides a detailed explanation of the methodologies and techniques available for systematic active fault mapping/studies.

Tsunami Monitoring

Tsunamis are infrequent in Indian history. However, the earthquake and resulting tsunami in 2004 demonstrated that the country is not immune to them. To mitigate the risks posed by earthquakes and tsunamis, India has developed several earthquake and tsunami forecasting systems. The Indian Tsunami Early Warning System (ITEWS) is a real-time system that uses seismic data to detect tsunamigenic earthquakes and to provide early warning of potential tsunamis. The ITEWS is operated by the Indian National Centre for Ocean Information Services (INCOIS) and is an approved Tsunami Service Provider of the Indian Ocean Tsunami Warning & Mitigation System (IOTWMS).[60]

As part of Intergovernmental Oceanographic Commission the ITEWC provides data on tsunamis to 25 Indian Ocean countries. Several innovative concepts in tsunami modeling, mapping of coastal inundation, decision support systems and SOPs have been introduced by INCOIS.

It has also established a Global Navigation Satellite System (GNSS) & Strong Motion Accelerometers in the Andaman and Nicobar Islands for quick and reliable estimation of near-source earthquakes. INCOIS has also carried out Multi-hazard Vulnerability Mapping (MVHM) along the Indian coastal mainland. The ITEWC, INCOIS also conducts workshops, training sessions and mock tsunami exercises to increase preparedness and is coordinating with coastal states/UTs to implement the UNESCO Tsunami Ready Program.[51]

A prototype unit of an indigenously developed Tsunami Bottom Pressure Recorder (BPR) Sagar-Bhoomi was successfully deployed off Chennai on 17th September 2022 to provide alerts of possible tsunamis.[52]

1.3

NATIONAL QUANTUM MISSION

FACTSHEET

Year of Union Cabinet Approval	2023
Nodal Agencies	• Department of Space, • Department of Atomic Energy, • Ministry of Electronics and Information Technology, • Department of Telecommunication, and • Department of Science and Technology
Financial Outlay	INR 6,003.65 crores over 7 years
Key Objective	To seed, nurture and scale up scientific and industrial R&D and create a vibrant & innovative ecosystem in Quantum Technology

Quantum technology is a rapidly emerging field that harnesses the power of quantum mechanics to create new and revolutionary technologies. Quantum mechanics is the study of how nature works at the smallest scales, and it is a very different world from the one we experience at the macroscopic scale.

Quantum technologies exploit the properties identified by quantum physics to provide new capabilities that have the potential to revolutionise many aspects of our lives, such as computing, communications, and sensing.[63] For example, quantum computers could be used to solve problems that are currently intractable for classical computers. Quantum communication networks could provide secure communication that is immune to eavesdropping and quantum sensors could be used to make measurements with unprecedented accuracy.

The potential applications of quantum technologies are vast. They could be used to develop new drugs, design new materials, and create new forms of AI. They could also be used to improve our understanding of the universe and our place in it.

The first quantum revolution brought technologies that are familiar to us today, such as nuclear power, semiconductors, lasers, magnetic resonance imaging, modern communication technologies or digital cameras and other imaging devices. The second quantum revolution[64] is characterised by manipulating and controlling individual quantum systems (such as atoms, ions, electrons, photons, molecules or various quasiparticles), allowing to reach the standard quantum limit; that is, the limit to measurement accuracy at quantum scales.

National Quantum Mission

The National Quantum Mission (NQM) is a major initiative of the GoI to accelerate the development of quantum technologies and applications in the country. The mission was approved by the Union Cabinet in February 2023, and it is scheduled to run from 2023 to 2031.

The mission aims to promote applied and translational research in quantum technology, while also supporting basic research. The mission will encourage directed research in collaboration with national academic and research institutions to develop specific quantum technologies and applications that align with the country's societal and economic needs. The mission also focuses on developing robust R&D and institutional infrastructure to facilitate accelerated research in quantum technology. Entrepreneurship development and integration of quantum technology into the startup ecosystem are key goals, with the potential for some startups to become global players. Human resource development is another area of focus, aiming to cultivate a talented workforce and build a strong knowledge base in research laboratories across the country.

The NQM has a total budget of INR 6,000 crores, and it will focus on four key areas through the development of four thematic hubs at top academic and National R&D institutes in the domains, on the following themes:

- **Quantum computing:** The mission will support the development of intermediate-scale quantum computers with 50-1,000 physical qubits. These computers will be used for a variety of applications, such as drug discovery, financial modelling, and artificial intelligence.
- **Quantum communication:** The mission will develop satellite-based quantum communication networks that can be used for secure communication and distributed computing. Satellite-based secure quantum communications between ground stations over a range of 2,000 km within India, long-distance secure quantum communications with other countries, inter-city quantum key distribution over 2,000 km as well as multi-node Quantum network with quantum memories are also some of the deliverables of the Mission.
- **Quantum sensing:** The mission will develop quantum sensors that can be used for applications such as precision agriculture, medical diagnostics, and environmental monitoring.
- **Quantum Materials & Devices:** The mission will help develop materials and devices such as magnetometers with high sensitivity for precision timing (atomic clocks), communications, and navigation. It will also support the design and synthesis of quantum materials such as superconductors, novel semiconductor structures and topological materials for the fabrication of quantum devices.

Image 19: Superconducting Quantum Computer Development at TIFR Mumbai and IISc, Bengaluru
(Source Credit: Prof. R. Vijayaraghavan, TIFR Mumbai)

Key objectives

- Development of intermediate scale quantum computers with 20-50 physical qubits (3 years), 50-100 physical qubits (5 years) and 50-1,000 physical qubits (8 years) in various platforms like superconducting and photonic technology.
- Development of satellite based secure quantum communications between two ground stations over a range of 2,000 kilometres within India as well as long distance secure quantum communications with other countries.
- Develop inter-city quantum key distribution over 2,000 km with trusted nodes using wavelength division multiplexing on existing optical fibre.
- Develop multi-node Quantum network with quantum memories, entanglement swapping and synchronised quantum repeaters at each node (2-3 nodes).
- Develop magnetometers with 1 femto-Tesla/sqrt(Hz) sensitivity in atomic systems and better than 1 pico-Tesla/sqrt(Hz) sensitivity in Nitrogen Vacancy-centers; gravity measurements having sensitivity better than 100 nano-meter/second^2 using atoms and atomic clocks with 10-19 fractional instability for precision timing, communications and navigation.
- Design and synthesis of quantum materials such as superconductors, novel semiconductor structures and topological materials for fabrication of quantum devices for development of qubits for quantum computing and quantum communication applications, single photon sources/detectors, entangled photon sources for quantum communications, sensing and metrological applications.

The NQM is a major step forward for India's quantum research and development efforts. The mission has the potential to make India a leading player in the global quantum race, and it could have a significant impact on a wide range of industries.

1.4

NATIONAL SUPERCOMPUTING MISSION

NATIONAL SUPERCOMPUTING MISSION

INFRASTRUCTURE | APPLICATIONS | R&D | HRD

FACTSHEET

Year of Union Cabinet Approval	2015
Nodal Agencies	Jointly by Department of Science & Technology and Ministry of Electronics and Information Technology Implemented by Centre for Development of Advanced Computing (C-DAC) and IISc, Bangalore
Financial Outlay	INR 4,500 crores over 7 years
Key Objectives	Infrastructure Applications R&D Human resource development

A farmer who is deciding when to sow a crop, a government launching a new national defence system and a petroleum engineer deciding where to drill for oil; what do they have in common? Chances are that the data that they are basing their decision on has been analysed by a supercomputer.

Supercomputers, as the name suggests, are very fast and high-capacity computers that can have very high computing performance generally due to the use of parallel processing, which is the use of multiple CPUs to solve a single calculation at a given time.

Supercomputers are used for complex mathematically intensive computations for simulations and modelling, and have wide-ranging applications such as in weather and climate forecasting, drug and disease modelling, petroleum and oil drilling, defence and security among others.

Supercomputing capabilities, measured in FLOPS or Floating operations per second, have increased exponentially since the 1940s when supercomputers were first built. Today, supercomputing capabilities are measured in Petaflops (10^{15}) and Exaflops (10^{18}).

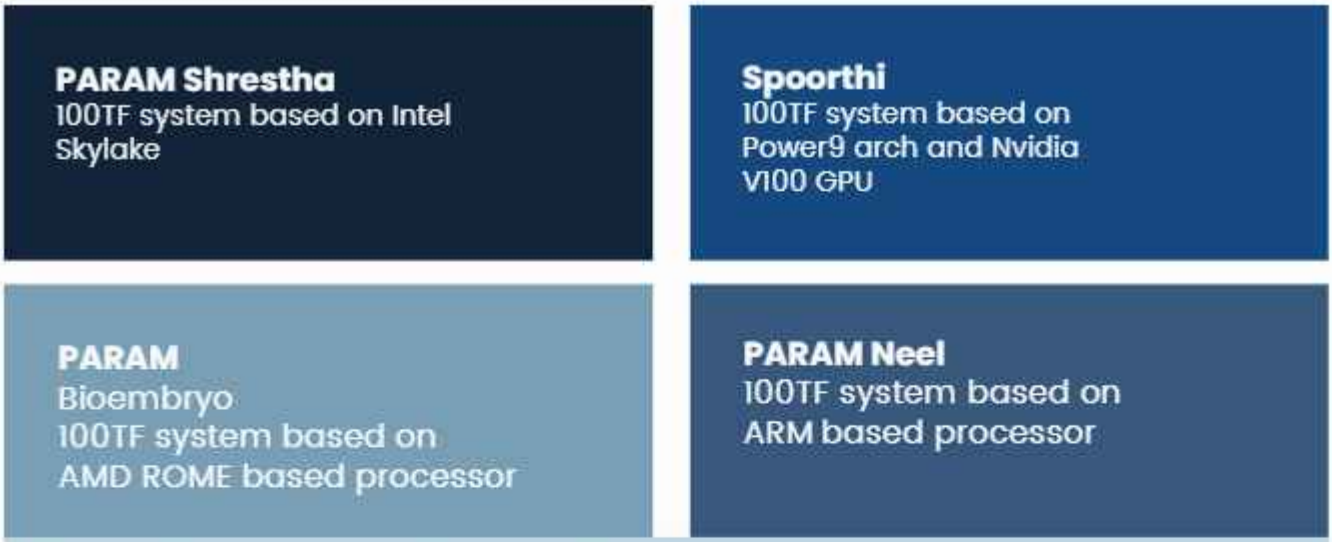


Figure 6: National Supercomputing Mission Infrastructure *(Source: National Supercomputing Mission website)*

India's supercomputing journey

The Centre for Development of Advanced Computing (C-DAC) set up a National PARAM Supercomputing Facility (NPSF) at C-DAC, Pune to facilitate the access of High Performance Computing (HPC) resources required to solve compute-intensive problems of researchers around the country. The users from various universities, IITs and other R&D institutions had the advantage of the reliability and availability associated with National Knowledge Network for accessing computing resources at NPSF.

In the early 2000s, ANURAG, BARC, C-DAC and NAL were active in design and development of supercomputers with performance in the range of few 100s of gigaflops to few teraflops. The PARAM Padma, with a peak speed of 1 teraflop in December 2002, was the first Indian supercomputer to feature on a list of the world's fastest supercomputers in June 2003. PARAM Yuva I, launched in 2008, ranked 68th in the TOP500 list released in November 2008 at the Supercomputing Conference in Austin, Texas, United States. With the launch of PARAM Yuva II in February 2013, India crossed the 500 teraflops milestone.

The deployment of Pratyush and Mihir in 2018, two of the most powerful civilian supercomputers in India, has also been a milestone for Indian supercomputing. Pratyush is located at the IITM in Pune, while Mihir is housed at the NCMRWF in Noida. Both supercomputers have a peak processing speed of 4 petaflops, making them among the top 100 most powerful supercomputers in the world. The two supercomputers are used to help model the quality of weather forecasts, including monsoons. They also support in forecasting of natural disasters such as cyclones, earthquakes and other extreme events.[65]

In 2015, the Ministry of Electronics and Information Technology (MeitY) under Government of India and Department of Science & Technology (DST) under Government of India announced a National Supercomputing Mission, a seven year program, worth INR 4,500 crores to propel India's supercomputing abilities.

The National Supercomputing Mission and its achievements

The National Supercomputing Mission has four pillars: Infrastructure, applications, R&D and Human Resource Development.

The Infrastructure pillar envisages the installation of more than 70 high performance computing facilities across the country for the use of the academic and R&D institutions. These supercomputers will be networked on the National Knowledge Network, which is a programme of the government connecting academic institutions and R&D labs over a high-speed network.

So far, supercomputing systems have been deployed at 18 institutions with a total supercomputing capacity of 24 PF under NSM Phase-I & Phase-II providing access to 99 academic and research institutes.

PARAM Shivay, the first supercomputer assembled indigenously, was installed in IIT BHU, followed by PARAM Shakti, PARAM Brahma, PARAM Yukti, PARAM Sanganak at IIT-Kharagpur IISER, Pune, JNCASR, Bengaluru and IIT Kanpur, IIT Hyderabad, NABI Mohali, C-DAC Bengaluru respectively.[66]

IISc Bengaluru has installed Param Pravega, one of the most powerful Indian supercomputers. Param Pravega, having a supercomputing power of 3.3 petaflops, is the largest supercomputer that has been installed in an Indian academic institution.[67]

India's newest and fastest supercomputer, PARAM-Siddhi AIRAWAT, has been ranked 75th in the 'TOP500 Supercomputer List – June 2023' declared at International Supercomputing Conference 2023 (ISC 23) at Germany. The supercomputer with Rpeak of 5.267 Petaflops and 4.6 Petaflops Rmax (Sustained) was conceived by C-DAC and developed jointly with support of DST and MeitY under NSM. The AI system will strengthen the application development of packages in areas such as advanced materials, computational chemistry & astrophysics, and several packages being developed under the mission of a platform for drug design and preventive health care system, flood forecasting package for flood-prone metro cities like Mumbai, Delhi, Chennai, Patna and Guwahati. This will accelerate R&D in our war against COVID-19 through faster simulations, medical imaging, genome sequencing and forecasting and is a boon for Indian masses and startups and MSMEs in particular.[68]

Image 20: PARAM Siddhi-Airawat (AI) supercomputing system PSAI of 8.5 Petaflops (410 AI petaFLOPS) is the fastest Supercomputer in India *(Source: Department of Science and Technology inputs)*

An additional capacity of 40 PF deployment is envisaged in Phase III of the mission thus increasing the total capacity to 64 PF, which is much higher than the originally envisaged capacity of 33 PF of the mission.

The applications pillar is focused on developing high-performance computing applications of national relevance. Application development in the domains of genomics, drug discovery, urban modelling, early warning systems for flood forecasting, seismic data analysis for oil & gas exploration, and telecom network optimisation has been taken up in consortium mode involving R&D and domain-specific user agencies of governmental organisations.

The R&D pillar is focused on indigenously developing the next generation of HPC technologies including areas such as the next-generation system architectures and prototypes, and power optimisation technologies among others. In this pillar, achievements include various supercomputing sub-systems (server, interconnect, system software stack, cooling system) that have been indigenously designed and developed. An indigenous server "Rudra" is being manufactured thus creating a supercomputing ecosystem in the country.

The development of an indigenous HPC processor (India's own processor) has also been initiated. A next generation indigenous HPC interconnect called "Trinetra" has been designed and developed in the country for efficient inter-node communication between compute nodes. This will help improve power efficiency and also support large-scale systems.[69]

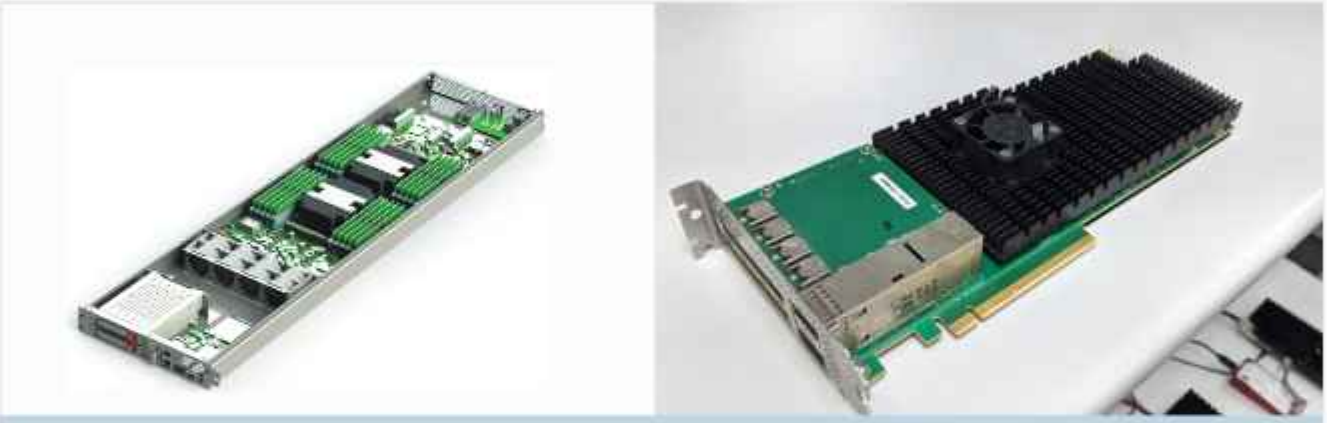


Image 21: Rudra (left) and Trinetra (right) *(Source: Department of Science and technology inputs)*

One of the key deliverables of the mission is the development of a highly professional HPC-aware human resource pool at all levels for meeting the challenges of the development of HPC applications as well as for managing, monitoring, and running such complex HPC systems. To date, 18,000 personnel have been trained in various aspects of HPC. This includes both computer science and non-computer science professionals.

1.5

NATIONAL GEOSPATIAL POLICY

Image 22: Representative image (Source: DST)

FACTSHEET

Evolution	Guidelines for acquiring and producing Geospatial Data and Geospatial Data Services including Maps (2021)
Year of Notification	December 2022
Nodal Agency	Department of Science and Technology
Institutional Partners	Survey of India, Key Nodal Ministries, Departments and industry associations
Mode of Implementation	Regulatory, liberalisation, government e-services and public goods
Key Objectives[70]	• By 2025, supportive legal and policy framework, improve access and quality of location data, introducing high accuracy Geoid for India. • By 2030, developing high-resolution topographical survey & mapping, high-accuracy Digital Elevation Model (DEM). • By 2035, developing high-accuracy Bathymetric Geospatial Data of inland waters and sea surface topography, survey and mapping of sub-surface infrastructure in major cities and towns and National Digital Twin of major cities and towns.

Whether it be taking taxis or ordering hot food from a neighbouring restaurant, the use of digital maps on phones has become an inseparable part of modern life, powered by new digital technologies. Many of us use maps to explore and discover new tourist locations, less afraid of losing our way in new locations than earlier. Precise location services are essential for both traditional and modern businesses, including agriculture, mining, construction, e-commerce services and logistics. Geospatial data is now widely accepted as a critical national infrastructure and information resource with proven societal, economic and environmental value that enables government systems and services, and sustainable national development initiatives, to be integrated using 'location' as a common and underpinning reference frame.

The earlier policies and procedures related to maps in India were restrictive, inheriting a framework from the British Raj era, which enabled the foreign rulers to restrict Indians from developing their maps. These policies were not updated for decades or more. The National Map Policy, 2005 had a provision for obtaining one-time clearance from the Ministry of Defence for all types of maps, which was still very onerous for citizenry and business, and did not yield substantive results. Other countries relaxed their geospatial rules, allowing businesses to develop powerful tools like mapping apps, enabled by powerful remote sensing capabilities. As recently as 2020, India was almost entirely reliant on foreign map-makers because domestic laws hampered the potential for domestic entrepreneurs and cartographers to operate even within their own national borders.

Recognising the importance of the geospatial sector in the development and growth of the economy of India, the government liberalised acquisition and production of geospatial data in 2021. Following this, the National Geospatial Policy was notified in 2022 which introduced a framework for the development of India's Geospatial capacities laying down the role of the government and opening the industry for the private sector.

According to one report,[71] India's total geospatial market (including both domestic and export markets) was estimated at almost INR 23,000 crores in 2019. India's total geospatial market is forecasted to rise to INR 37,16,000 crores by 2025, with the enabling policy environment and the gradual transition of the industry to offer services and solutions to the worldwide market. Further, India's domestic geospatial market is estimated to be INR 23,09,000 crores by 2025 and INR 40,60,000 crores by 2030.

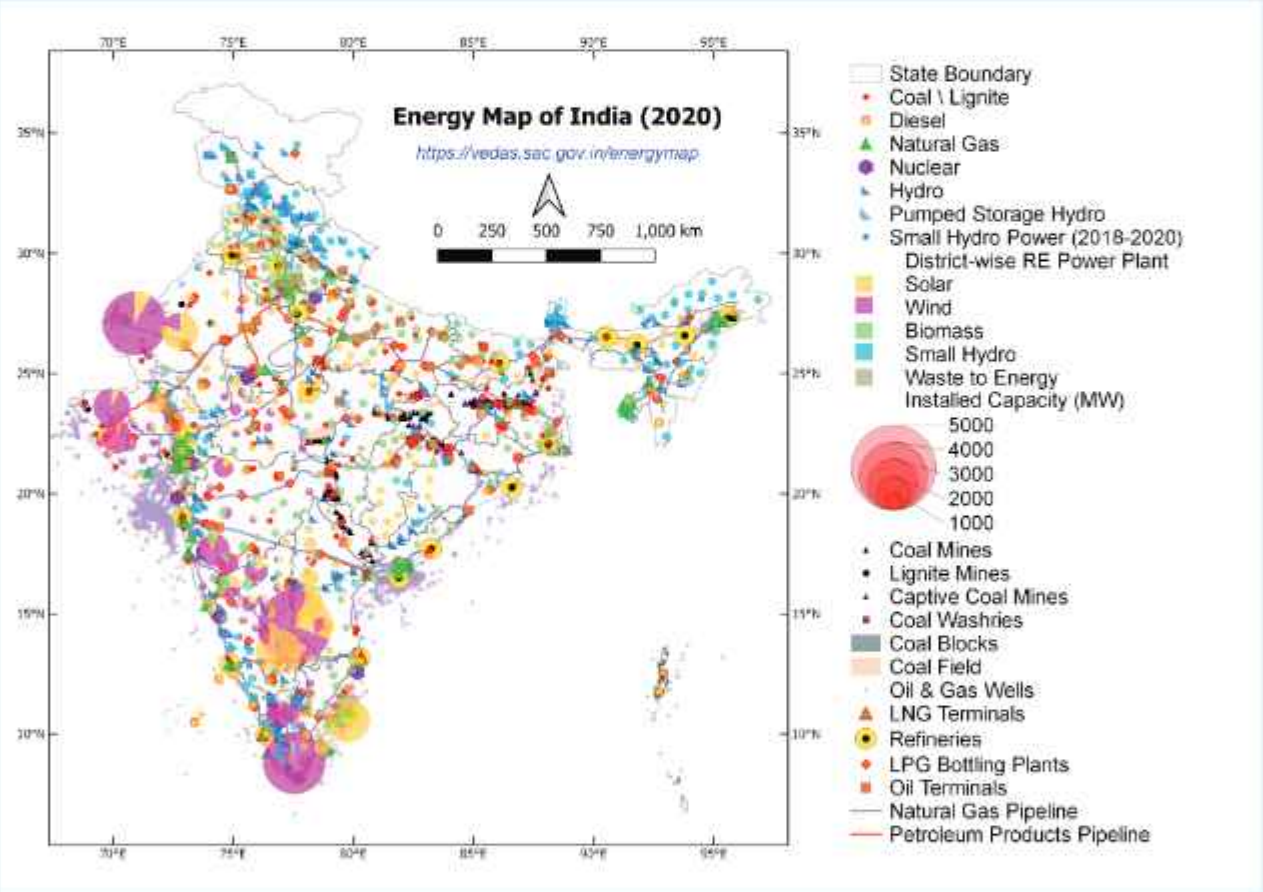


Image 23: Example of Geospatial capabilities: Energy Map of India, NITI Aayog and ISRO
(Source: NITI Aayog Energy Map of India portal)

Key achievements

The liberalisation of the Indian geospatial market started recently, in 2021. However, one can see key achievements in the sector. For instance:

- **Attracting investments:** Private companies and startups based in India can attract investments for conducting geospatial mapping for their future commercial use. For instance, Genesys International has invested and raised investments for obtaining surveying sensors for aerial and terrestrial platforms. Similarly, MapmyIndia received bids worth INR 1.13 lakh crores through IPO in 2021.

- **Government mapping projects:** Government schemes for land mapping such as the Svamitva scheme (worth INR 250-300 crores), the Karnataka Land Resources mapping scheme (worth INR 500 crores) and the Andhra Pradesh Land Resources mapping scheme (worth INR 300 crores), have been initiated under the National Geospatial Policy.

- **Employment generation and capacity building:** As per the Geospatial Artha Report, in 2021, the Indian geospatial industry employed 4,70,000 people including domestic employment, export services and employees in the Government services; and this number is estimated to have increased to approx. 5,45,000.

- **Improvements in data collection and access:** The GoI has taken many initiatives under the National Geospatial Policy to provide to high-quality data. For instance, Survey of India (SoI) has launched a portal to provide easy access to SoI products to all citizens and government organisations in India. This Portal provides various digital geospatial products (free as well as at fair & transparent prices) to the users.

Conclusion

With the two-prong strategy of liberalisation and identification of 14 National Fundamental Geospatial Data Themes across various sectors, the government aims to enhance India's geospatial prowess in an accelerated manner. More and more start-ups, companies, academia, and non-profit organisations are set to participate in and reap the benefits of this policy. In addition to trade-related uses, the National Geospatial Policy is set to enable the provisioning of public goods to the citizens.

Many government schemes related to inclusion and access to public goods involve the utilisation of geospatial mapping. For instance, the Smamitva scheme aims to use geospatial mapping to establish clear ownership of property in rural inhabited areas, by mapping land parcels using drone technology and providing 'Record of Rights' to village household owners with issuance of legal ownership cards to the property owners.[72] Similarly, the PM Gati Shakti Master Plan for multi-modal connectivity, which aims to connect the various stakeholders in India's infrastructure development uses geospatial technology.[73]

1.6

ARTIFICIAL INTELLIGENCE

AI is the ability of a digital computer or computer-controlled robot to perform tasks commonly associated with intelligent beings such as the ability to reason, discover meaning, generalise, or learn from past experience.[74] AI is a kinetic enabler to leapfrog traditional development barriers and catalyse large scale socioeconomic transformation in the country. AI is expected to add $967 billion[75] to the Indian economy by 2035 and $450-500 billion to India's GDP by 2025, accounting for 10% of the country's $5 trillion GDP target. AI has the potential to impact every aspect of citizen's life from education, to agriculture, retail, healthcare, and urban governance amongst others.

Given the relatively rapid development and deployment of AI globally, there is a need for nations to catch up on their regulatory governance with this evolution. India is one of the pioneers in the field. Being one of the founding members of the Global Partnership on AI (GPAI) enables India to represent the perspectives of the Global South and developing economies in global AI discourse and lead the responsible development and deployment of AI globally. As the elected Council Chair of the GPAI, India will provide strategic direction to GPAI aligned with these motivations while also hosting the annual GPAI Summit in 2023. As a Council Chair for GPAI till November 2025, India will also provide strategic direction to the four expert working groups of GPAI and ensure that the global model for AI governance is aligned with its domestic model and national interests.

MeitY is the nodal ministry responsible for implementing a comprehensive program to catalyse AI innovation and ensure the responsible and transformative use of AI for All.

Image 24: Bhashini, India's National Public Digital Platform for languages (Source: Bhashini website)

Table 4: Key initiatives and activities by the Government of India for promoting AI

Initiative	Description	Key achievements
National Program on Artificial Intelligence (NPAI)	An institutional framework for – • Data Governance for AI and emerging technologies (National Data Management Office), Scaling AI solutions for social transformation (National Centre on AI), • Building skilling infrastructure for foundational data and AI jobs, • Empowering government officials with Data and AI skills, • Building institutional mechanisms to enable Responsible AI	
National Data Governance Policy (NDGP)	• Draft NDGP aims to enhance access, quality, and use of non-personal data • The National Data Management Office (NDMO) provides an Institutional Framework for data governance in the country including providing standardised data management and security standards, privacy preservation tools and anonymisation standards that prioritise privacy, security and trust NDMO will curate quality datasets through the India Datasets Program and augment data accessibility through the India Data Platform	
Digital India Bhashini	• To create a 'voice-based internet' accessible in vernacular Indian languages and build multilingualism by developing the next generation of 'conversational' government apps and websites • Enable the citizen to access digital services in their vernacular language to further increase digital inclusion and accessibility • Build speech-to-speech machine translation systems for various Indian languages and dialects and evolve a Unified Language Interface (ULI)	Launched in July 2022

Initiative	Description	Key achievements
National Portal on AI	MeitY has launched the "National AI Portal" (https://indiaai.gov.in/) which serves as a comprehensive repository of AI initiatives in the country. The portal acts as a single point of reference for individuals, researchers, and industry professionals seeking information about AI initiatives in India, including academic research, startups, policy initiatives, and other related information.	The number of listings: • 184 Government initiatives, 2185 national and international articles, • 983 news, • 297 videos, • 148 research reports, • 466 Startups
FutureSkills Prime:	MeitY & NASSCOM have jointly initiated a programme titled FutureSkills PRIME, a B2C framework for re-skilling/up-skilling of IT professionals in 10 Emerging areas including Cloud Computing and AI.	• 14.24 Lakhs candidates have signed up on the FutureSkills PRIME Portal, out of which, 2,57,307 candidates have completed their course • 1,885 Trainers and 10,028 Government Officials have been trained on these technologies by National Institute of Electronics & Information Technology (NIELIT)/C-DAC Resource Centers, and • Around 11,51,143 unique learners have collectively earned 68,15,082 'badges' in recognition of having completed bitesized digital fluency content

Initiative	Description	Key achievements
Visvesvaraya PhD Scheme	The Scheme aims to enhance the number of PhDs in Emerging Technologies like AI, Robotics, Blockchain, Electronics System Design & Manufacturing (ESDM) and IT/IT Enabled Services (IT/ITES) in the country.	• Phase-I of the Scheme supported 757 PhD candidates who have completed PhD/submitted their theses • Phase-II launched
Youth for Unnati and Vikas with AI (YUVAI)	In collaboration with industry partners, MeitY has launched 'Youth for Unnati & Vikas with AI' – a national program for all school students between eighth to twelfth standards to create an AI ready workforce for the future. This program aims to provide an equal opportunity to school-going children - in urban, rural and remote corners of India - to become human-centric designers trained in the responsible development and deployment of AI for social good.	• Launched in 2020, 52,628 students registered for the program from 35 states and UTs (5,724 cities) • The top 20 ideas represented by 27 students were shortlisted as the winners and showcased as part of Azadi Ka Digital Mahotsav
AI Research, Analytics and Knowledge Dissemination Platform (AIRAWAT)	MeitY through C-DAC has initiated a proof-of-concept project on AIRAWAT (AI Research, Analytics and Knowledge Dissemination Platform) for providing a common computing platform for AI research and knowledge assimilation. This AI Computing infrastructure will be used by all Technology innovation hubs, Research Labs, Scientific Communities, Industry, and Startups institutions with National Knowledge Network.	• The PoC for AIRAWAT is developed with 200 petaflops Mix Precision AI Machine which will be scalable to a peak compute of 790 AI petaflops

Future roadmap

The whole-of-government approach is towards ensuring the comprehensive development of AI across sectors. India AI is conceptualised as an umbrella program that will integrate various national-level AI initiatives. The program aims to build the next 100 AI Unicorns in the country and make India the global leader in AI innovation, research, and governance. The priority areas identified to achieve the vision of India AI are:

- **AI Innovation -** For realising the vision 'Make AI in India and Make AI work for India', three Centres of Excellence (CoEs) for AI will be set up in educational institutions. These CoEs will operate under a hub and spoke model, galvanise an effective AI ecosystem, and nurture quality human resources in the field.

- **Data for AI -** Since data is the essential prerequisite for the AI and Emerging Technologies ecosystem, the GoI is conceptualising the India Datasets Platform and Program. ***The India Datasets Platform (IDP)*** will enable all government and private entities to share, discover, and use data/artefacts/metadata/APIs through an interoperable, robust, and secure system. The platform will also implement the IDP which will catalyse the research and innovation ecosystem by providing datasets curated for AI to stakeholders who may unlock the potential of this data for national development.

- **Future Skills -** For realising the full transformative potential of AI the Indian workforce must be prepared with the requisite skillset to keep pace with the advancements in AI. A roadmap for the development of the skill and talent for AI to enable skilling, reskilling and upskilling taking into account the existing capacity and skill ecosystem in the country will be undertaken.

- **AI Financing -** To bolster the growing AI startup ecosystem in India, funding is essential to fuel their R&D efforts, acquire and manage data, access infrastructure and computing resources, attract and retain talent, drive marketing and business development, protect intellectual property, and scale their operations.

- **AI Compute –** Democratising access to AI compute infrastructure is critical for ensuring a level AI playing field and global competitiveness of Indian AI Startups. Leading AI compute infrastructure will act as the kinetic enabler for the startup and innovation ecosystem, helping organisations develop commercially viable AI applications.

Image 25: CDAC Pune, where AIRAWAT AI Supercomputer is housed *(Source: CDAC Pune website)*

1.7

NATIONAL MISSION ON INTERDISCIPLINARY CYBER-PHYSICAL SYSTEMS

FACTSHEET

Year of Union Cabinet Approval	2018
Nodal Agency	Department of Science & Technology
Financial Outlay	INR 3,660 crores over 5 years
Key Achievements	• Successfully developed and produced 276 technologies and 512 technology products. • Provided support to 339 startups and facilitated entrepreneurship development. • High-end skill development of individuals along with 116 international partnerships.

The worlds of atoms and bytes are often considered to be separate. However, sensors, internet-connected devices and ubiquitous data connectivity have started to bind these worlds together.

NM-ICPS is an ambitious program that focuses on Interdisciplinary Cyber-Physical Systems (CPS) – the integration of computing, networking, and physical processes. CPS combines the digital and physical worlds, enabling intelligent and interconnected systems. NM-ICPS encompasses technologies like AI, the IoT & Robotics which make it crucial for advancing India's development goals in sectors such as healthcare, agriculture, industry 4.0, transporation, environment & pollution, infrastructure & energy, education, judiciary & legal, security, and communication. It aims to develop technology platforms for R&D, product development, startups, and commercialisation while promoting collaboration among academia, industry, government, and international organisations.[75]

Implemented through 25 Technology Innovation Hubs (TIHs), NM-ICPS drives India's technological growth across various sectors in line with national priorities.[77] These hubs are now fully operational and are being proactively facilitated, mentored, and reviewed to ensure they achieve the mission's targets, with a strong focus on translational research. NM-ICPS is creating direct linkages between the TIHs and all stakeholders, including line ministries, state governments, industry, PSUs, and startups, through national-level events like workshops and expos. The mission's Expert Committees, such as the Mission Governing Board, Scientific Advisory Committee, and Inter-Ministerial Coordination Committee, hold frequent meetings to guide the mission's progress and suggest the way forward. The achievements of all TIHs are being showcased through quarterly bulletins, the NM-ICPS portal, and various social media platforms, promoting collaboration and fostering innovation in the field of Interdisciplinary CPS.

Image 26: The Technology Innovation Hub setup at IIT Bombay
(Source: Technology Innovation Hub IIT Bombay Twitter)

Table 5: Achievements and outputs

Output	Description
Development of technologies/ technology products	The program has successfully developed and produced 276 technologies and 512 technology products.
Support to startups and entrepreneurship development	The program has provided support to 339 startups and facilitated entrepreneurship development.
Increase in CPS and related researchers' base	The program has contributed to a significant increase in the number of CPS and related researchers by 1,019.

Output	Description
High-end skill development	The program has enabled the high-end skill development of 54,502 individuals.
Establishment of TIHs	The program has established 25 TIHs to foster innovation.
Job creation	The program has created 13,259 jobs in the short term (5 years) and has the potential to create 240,000 jobs in the long term (9 years).
Publications, IPR, and other intellectual activities	The program has generated 1,128 publications, IPR, and other related intellectual activities.
International collaborations	The program has undertaken 116 international collaborations to foster global partnerships.

Image 27: Asha, a robot nurse being developed in ARTPARK, an AI & Robotics research translation initiative at IISC Bangalore, seed-funded by NM-ICPS (170 crores) *(Source: Twitter details – IISc Kernel Indian Institute of Science)*

Key achievements and the way ahead

NM-ICPS focuses on equipping key Indian sectors of healthcare, agriculture, industry 4.0, transporation, environment & pollution, infrastructure & energy, education, judiciary & legal, security, and communications with intelligent and interconnected systems. This is a key step towards developing technologies/ technology products and their commercialisation in line with National priorities. Through extensive research and development in AI, Machine Learning, Robotics, and more, the innovation focus of the mission is critical to improving India's technological capabilities. It supports startups, job creation, and international collaborations, contributing to the country's overall development and prosperity.

NM-ICPS represents a pivotal endeavour that unites the worlds of atoms and bytes through the integration of CPS - through AI, the IoT, & Robotics. By focusing on R&D, product development, and startup innovations NM-ICPS is set to drive India's development goals forward. The mission fosters collaborations between industry, academia, government, and international organisations, paving the way for groundbreaking technological developments. As India looks forward to the coming decade, this mission holds the key to transformative advancements, propelling India towards technological excellence.

1.8

ADVANCED MATERIALS AND MANUFACTURING

INTRODUCTION

India's advanced materials and manufacturing sector has witnessed significant achievements through government interventions in various domains such as Supercapacitors, Additive Manufacturing, Advanced Coatings, Fuel Cells, Rare Earth Magnets, Advanced Ballistic Materials and Glass & Ceramicst.

1. SUPERCAPACITORS

Supercapacitors are highly valued as energy storage devices in India due to their high power density, long cycle life, fast charge and discharge capabilities, instantaneous high current discharge, affordability, and eco-friendliness. They have applications in consumer electronics, automotive industry, communications, medical equipment, national defence, and military equipment. In India, supercapacitors play a crucial role in sustaining peak loads and providing backup power, ensuring uninterrupted operation in battery-powered industrial applications. The introduction of supercapacitors has the potential to revolutionise the automobile industry by enabling dynamic braking systems and enhancing static memories.

DST has been actively promoting research and development in supercapacitor technology through various funding schemes and initiatives.

Key government interventions

The Indian government initiatives in the sector include funding research and academic institutes through government-funded projects from the DST. Notably, an important milestone in the advancement of supercapacitors is the funding provided to the International Advanced Research Centre for Powder Metallurgy and New Materials (ARCI). This funding has facilitated the development of carbon-based supercapacitors, representing a significant step forward in the progress of supercapacitor technology in India.

Image 28: Petcoke derived high energy supercapacitor developed at ARCI
(Source: Department of Atomic Energy website)

Key achievements

- ARCI successfully developed supercapacitors with a capacitance of 1,200 farad (F), matching the capacity of commercially available supercapacitors from the US. Furthermore, ARCI is collaborating with a startup to harness the power of supercapacitors for drone applications, encompassing both societal and strategic purposes.
- ISRO has developed supercapacitor processing technology at the Vikram Sarabhai Space Centre (VSSC). This technology enables the production of supercapacitors with different capacitance values, with a maximum capacitance of 500 F. These supercapacitors are designed to cater to specific applications related to space missions and societal needs.
- In the private sector, GODI India, based in Hyderabad, has successfully manufactured high-power supercapacitors with a capacitance of 3,000F. The company plans to establish a 200kWh supercapacitor production facility to cater to regional demands and export markets.
- SPEL, a Pune-based industry, has achieved the milestone of manufacturing India's first supercapacitor. SPEL is collaborating with various government research organisations, universities within and outside India to further advance supercapacitor technology.

2. ADDITIVE MANUFACTURING

Additive Manufacturing, popularly known as 3D printing, has emerged as a disruptive technology across industries. Unlike subtractive manufacturing, which involves cutting, drilling, or machining materials to create a desired shape, additive manufacturing builds objects layer by layer using digital design data. This technology has gained immense popularity due to its ability to create complex and customised parts with reduced waste, increased efficiency, and improved design flexibility. Additive manufacturing has found applications across various industries, including aerospace, automotive, healthcare, and consumer goods, and continues to evolve with advancements in materials, processes, and applications. The additive manufacturing industry in India is witnessing growth driven by factors such as increasing adoption and awareness across various sectors, active research and development efforts, the emergence of startups and entrepreneurial ventures, government initiatives supporting the industry, establishment of infrastructure and skill development programs. However, challenges related to raw materials, infrastructure, standardisation, and regulations need to be addressed. Overall, India's additive manufacturing sector presents opportunities for growth and technological advancements.

Image 29: Additive manufacturing printers
(Source: Ministry of Electronics and Information Technology National Strategy for Additive Manufacturing website)

Key government interventions

The Indian government has formulated a comprehensive National Strategy for Additive Manufacturing,[78] which provides a roadmap for the development and adoption of 3D printing technologies in the country. Released in February 2022 by MeitY, it lays out a comprehensive roadmap to foster the growth of additive manufacturing in the country. The strategy aims to position India as a global hub for additive manufacturing and outlines key focus areas such as R&D, skill development, infrastructure creation, industry collaboration, and policy reforms.

Based on the tenets of 'Make in India' and ***'Aatmanirbhar Bharat'***, the strategy seeks to harness the potential of additive manufacturing to drive innovation, create employment opportunities, and enhance competitiveness in domestic and international markets.

Current status

Additive Manufacturing (AM) in India is relatively a new entry in the industry. But, in the past few years, many innovative AM systems have been launched in the Indian market to increase their popularity and usage among people. AM technology has gained a lot of momentum in the country over the past few years, with several institutions in India playing a significant role in the development and implementation of additive manufacturing technology. These institutions contribute to the research, development, and application of different additive manufacturing techniques. The AM market in India is experiencing robust growth, with a steady annual increase of 20%. Market reports indicate that the AM market is projected to surge from $12.6 billion in 2020 to an estimated $37.2 billion by 2026.

3. ADVANCED COATINGS

In the last decade, India has witnessed significant developments in the field of advanced coatings. These coatings enhance the performance, durability, and functionality of various products and surfaces across industries such as automotive, agriculture, power generation, and aerospace. One of the key contributors to the development of advanced coatings in India is the ARCI. ARCI has pioneered the research and development of novel coating technologies, including detonation spray, cold gas dynamic spray, and electron beam on physical vapour deposition. These technologies offer superior properties and performance compared to traditional coatings, opening up new possibilities for industries in automotive, aerospace, agriculture, power generation, and other sectors.

Key government interventions

The government has played a significant role in supporting the development of the advanced coatings sector. Efforts have been made to promote indigenisation of coating technologies, reducing dependence on imported coatings. ARCI, with its expertise, has been instrumental in guiding Indian industries towards the migration and application of advanced coatings for specific applications. The government's initiatives to raise awareness through digital and print media, as well as organising workshops, have facilitated knowledge sharing and technology adoption.

The establishment of research infrastructure, funding programs, and collaborations between industry, academia, and research institutions have accelerated the development and commercialisation of advanced coatings in the country. These initiatives have stimulated innovation, created employment opportunities, and positioned India as a hub for advanced coating technologies.

Key achievements

ARCI has played a vital role in the development and implementation of various advanced coating technologies, including detonation spray, micro arc oxidation, and electro spark coatings, in Indian industries nationwide. This successful transfer of technologies has led to the creation of employment opportunities, increased revenue, and self-sufficiency in meeting the requirements of industries such as thermal power plants, aerospace, and automotive. Consequently, ARCI has emerged as a global leader in the field of advanced coatings, showcasing its expertise and contributions to the industry with several successful research outcomes to its credit.[79 80 81 82]

Image 30: Helicopter Engine compressor with partially loaded TiN coated blades for real-time flying test
(Source: Department of Science and Technology website)

Conclusion

India has achieved significant milestones in the field of advanced coatings, leading to enhanced industrial capabilities and self-sufficiency. The successful transfer of technologies by institutions like ARCI has resulted in the widespread adoption of advanced coatings across sectors. To further enhance the field's application and capabilities, it is crucial to facilitate focused R&D funding for advanced coatings at the national and international levels through government policies. Nurturing the next generation of leadership and addressing new requirements beyond standard levels are important challenges to be addressed. Moreover, the high cost of relevant high-tech infrastructure necessitates additional support from the government in the form of extramural/grant-in-aid, which will provide a significant thrust to promote the field of advanced coatings in India. By addressing these challenges and fostering continued support, India can strengthen its position as a global leader in advanced coatings and drive innovation in the sector.

4. FUEL CELLS

Fuel cell technology is of great importance to the development goals of India. As the third-largest consumer of imported oil, India faces the challenge of meeting increasing energy demand while also decarbonising various sectors and ensuring energy security. To achieve sustainable growth, a non-polluting, efficient, and clean fuel like hydrogen is necessary.

Hydrogen fuel cells offer high efficiency, zero emissions, and continuous power as long as fuel is supplied. Hydrogen fuel cells can be utilised across all energy sectors, including stationary power generation, transportation, backup power, and portable applications.

Key government interventions

Image 31: India's first hydrogen fuel cell powered bus flagged off in 2018
(Source: Indian Oil Corporation website)

India has adopted a comprehensive approach to the development of hydrogen fuel cell technology. This includes indigenous development of materials, components, stacks, and system integration. Key initiatives have been taken to set up automated assembly lines for manufacturing Proton Exchange Membrane Fuel Cells (PEMFC) and to transfer technology for components and systems.

To support the development of hydrogen fuel cell technology, the Indian government launched the National Hydrogen Energy Mission in 2021. This mission aims to promote the use of hydrogen as a clean energy source, address energy security, and reduce greenhouse gas emissions. Additionally, significant investments have been made in R&D initiatives to enhance hydrogen fuel cell technology in India.

Pilot projects for hydrogen fuel cell powered vehicles, such as buses, have been initiated in cities like Delhi, Mumbai, and Bengaluru. Hydrogen fuel cells are also being explored for offgrid and distributed power generation, particularly in areas with limited grid connectivity. The government has introduced supportive policies, including financial incentives, tax benefits, and subsidies to promote research, development, and deployment of hydrogen fuel cell systems.

Table 6: Current status and achievements[83]

Institute/ Organisation	Main Focus Area(s)	Achievements/Remarks
Central Electro Chemical Research Institute (CECRI), Chennai	PEMFC, Direct Methanol Fuel Cell (DMFC) DBC, hydrogen generation	Developed a 1 kW PEMFC stack, Developed a 5 kW PEMWE
Centre for Fuel Cell Technology (CFCT) Chennai	PEMFC, hydrogen generation	Developed PEMFC stacks up to 5 kW, Grid independent power systems (3 kW), and Fuel cell systems for transport applications with Mahindra Rise and Reva
Central Glass & Ceramic Research Institute (CGCRI), Kolkata	Solid Oxide Fuel Cells	Developed electrode and membrane materials for high-performance SOFCs and Low Temperature SOFC. 400 W SOFC stack developed
SPIC SF, Chennai	PEMFC, DMFC, hydrogen generation	Developed 5 kW PEMFC stacks, 250 W DMFC Stack, PEM-based water and methanol electrolyzers, fuel cell-based stationary applications such as UPS
IIT Bombay	PEMFC, DMFC, Intermediate Temperature Solid Oxide Fuel Cells	PEMFC system development, catalysts for PEMFC, working on HT-PEMFC and IT-SOFC
IIT Delhi	PEMFC, Direct Alcohol Fuel Cells, hydrogen generation, SOFC	Developed DEFC with a power density of 70 mW/sq.cm, electrode-catalysts, developed direct glucose fuel cells, non-PGM OR catalyst and micro fuel cell for MEMS, anode materials for hydrogen generation using PM water electrolyzer, anode material for direct hydrocarbon SOFC and low-temperature SOFC.

Institute/ Organisation	Main Focus Area(s)	Achievements/Remarks
IIT Madras	PEMFC, DMFC, SOFC	Developed a DMFC with nonnoble cathode catalyst with 340 mA/sq.cm (0.6 V) at 80 oC, non-PGM catalyst for PEMFC, SOFC material research
NCL, Pune	PEMFC	Prepared thermally stable PBI membranes, demonstrated a 350 W (15 cells) PBI-based PEMFC stack
NMRL, DRDO, Mumbai	PAFC, PEMFC	Developed and demonstrated 700-1000 W capacity PAFC-based UPS/generators. 1.2 kW PAFC system integrated into an electric vehicle developed under DRDO-REVA joint project, development work on PEMFC and SOFC
BARC, Mumbai	SOFC, PEMFC	SOFC material and tubular SOFC are under development
IISc, Bangalore	PAFC, DMFC, PEMFC	Developed PAFC with a power density value of about 560 mW/sq.cm.
Mahindra Rise	Hydrogen IC engines	Developed hydrogen-powered Alfa 3 wheeler vehicle, developing battery-powered electric hybrid vehicle
TATA Motors	Fuel cell technology for transport applications	Developing a fuel cell-based city bus, project on using hydrogen blends as fuels. TATA Teleservices is involved in the demonstration of fuel cell technology for mobile tower backup power
Indian Oil Corp. Ltd	Hydrogen infrastructure, hydrogen for the transport sector	Setup hydrogen dispensing stations, HCNG usage in 3-wheeled vehicles and light-duty buses

Institute/ Organisation	Main Focus Area(s)	Achievements/Remarks
Reliance Industries Ltd.	PEMFC for stationary applications, SOFC	Joined the NMITLI project for indigenous PEMFC technology development as the industrial partner established a fuel cell R&D lab in Mumbai
REVA (Own by Mahindra Rise)	Fuel cell-based small cars	Developed a car with NMRL with 1 kW PAFC stack on board, involved in a similar project with CFCT.
BHEL	PAFC, PEMFC, SOFC	Developed a 50 kW PAFC power plant, developed 1 kW PEMFC modules and a 3 kW PEMFC power pack, partner institute in the development of a 5 kW PEMFC system under the NMITLI project
Nissan India	PEMFC technology for automobile	Working on membrane development for PEMFC technology, studying membrane degradation
ACME Telepower	Fuel cells for backup power	Joint venture with Ballard power systems Inc. and Ida-Tech to set up a high volume low-cost fuel cell systems for mobile tower backup power
Eden Energy (India) Pvt. Ltd.	Hydrogen for the transport sector	Involved in the production of Hythane, an agreement was signed with Ashok Leyland for the supply of Hythane to be used in natural gas-powered buses
Gas Authority of India Limited	Hydrogen Infrastructure	The main player in the supply of suitable fuels, including hydrogen, natural gas, propane, butane, and methanol
Bloom Energy (India) Private Limited	SOFC	Working on testing and characterization of SOFC technology

Institute/ Organisation	Main Focus Area(s)	Achievements/Remarks
Daimler Research Center (DMRC), Bangalore	Fuel cell for transport applications	Setup an outsourcing R&D center in Bangalore, considering launching a commercial fuel cell vehicle in India
ISRO	Application of PEMFC powering automatic weather station, PEMFC use space station and man mission	100 W PEMFC system is developed for automatic weather station

5. RARE EARTH MAGNETS FOR EV TRACTION MOTOR APPLICATION

Rare earth magnets, specifically neodymium-iron-boron (Nd-Fe-B), are crucial for electric vehicle (EV) traction motor applications due to their exceptional magnetic properties in addition to high magnetic strength, compact size, and lightweight characteristics.

Image 32: High Energy Rare Earth permanent magnets *(Source: Bhabha Atomic Research Center inputs)*

In EV traction motors, rare earth magnets generate a powerful magnetic field, allowing efficient power conversion and delivering a significant amount of torque. This translates to improved motor performance, enhanced acceleration, and increased energy efficiency. The compact size and lightweight nature of these magnets also contribute to reducing the overall weight of the motor, making the EV more energy-efficient and extending its driving range.

The R&D of rare earth magnets, particularly for the manufacturing of EV traction motors, is of significant importance. India is anticipating substantial market demand for Nd-Fe-B magnets, especially for EV applications, reaching 10 kt per annum by 2030. Currently, the entire demand is met through imports. Many initiatives have been taken towards indigenising the production of rare earth magnets in India, reducing dependency on imports, and meeting the growing demand for EV applications.

Key government interventions

ARCI has taken a unique approach by establishing a pilot-scale manufacturing plant for Nd-Fe-B magnets. This process differs from the conventional powder metallurgy technique used globally.

A tripartite agreement has been signed between BARC, Indian Rare Earths Limited (IREL), and Ashvnini Magnets Pune for the extraction of rare earth materials. Additionally, ARCI has received funding from Science and Engineering Research Board (SERB) to set up a pilot plant with a manufacturing capacity of 3kg/day.

The institutional partners involved in this development include ARCI, IREL, BARC, Defence Metallurgical Research Laboratory (DMRL), and Ashvini Magnets, Pune. Each partner has played a crucial role in contributing to the research, development, and implementation of the novel manufacturing process for Nd-Fe-B magnets.

BARC has established a manufacturing plant in Vizag for rare earth magnets, specifically Sm-Co magnets. Additionally, the Defence Metallurgical Research Laboratory has developed the necessary expertise for the production of Nd-Fe-B magnets using conventional technology.

Current status

Currently, there are no commercial rare earth magnet manufacturers in India. Some companies import Nd-Fe-B block magnets from China, slice them into required shapes and sizes, and coat them with nickel for local supply. DMRL produces Sm-Co magnets on a small scale for strategic applications. IREL is collaborating with BARC and DMRL to establish a 3-ton Sm- Co magnet manufacturing plant. DMRL has announced the availability of Nd-Fe-B magnet manufacturing technology, and IREL has called for expressions of interest to set up an indigenous Nd-Fe-B magnet manufacturing plant. Additionally, Ashvini Magnets Pvt. Ltd. has signed an agreement with BARC and IREL for oxide-to-metal conversion technology. With the national focus on electric vehicles and "Make in India," establishing Nd-Fe-B magnet manufacturing technology is crucial to meet future demand.

Conclusion

India's rare earth metals industry for EV traction motor applications faces challenges due to China and Japan's dominance in permanent magnet manufacturing. Challenges include demonstrating pilot-scale magnet manufacturing technology, ensuring a consistent supply of rare earth materials, and addressing the limited availability of Dysprosium. Strategies should include supporting technology development, establishing a secure supply chain, and exploring international collaborations. These efforts will enhance India's capabilities in the industry and meet the demand for EV traction motors.

6. ADVANCED BALLISTIC MATERIALS

A ballistic armour or a Bullet Proof Jacket (BPJ) is the operational need for our Armed Forces to protect their lives and vital organs from injury caused by bullets or fragments of grenades or improvised explosive devices. The demand for a large number of BPJs required for our military and paramilitary forces is met mostly by using imported materials. While the assembly of the BPJs is carried out by a few Indian companies in the country, many of the BPJs are imported with high costs. It is the need of the hour that the assembly as well as the manufacturing of the raw materials for the body armour is taken up in India.

Prior to 2014, Indian Forces used to wear BPJs, weighing in the range of 14-17 kgs. These BPJs used steel plates and aramid fabrics initially. BPJs were not comfortable for movement as they were heavy and bulky. The steel plates were replaced by ceramics like alumina. However, these BPJs manufactured in India using imported raw material were unable to provide protection against higher calibre bullets such as hard steel core AK-47 bullets. Therefore, light-weight, and high-cost BPJs were imported from countries like US, Israel and other European countries for special operational needs. Most of them used silicon carbide plates and ultra-high molecular weight polyethylene (UHMWPE) sheets to stop the bullets.

Image 33: Bhabha Kavach
(Source: Bhabha Atomic Research Center inputs)

Key government intervention

With the objective of developing light-weight, import substitute, multi-hit capable BPJs, efforts were made to develop indigenous materials and designs for BPJs. The existing knowledge and expertise on special materials were utilised to fulfil the tactical need of the BPJs.

BARC developed expertise in fabricating hot-pressed boron carbide ceramic shapes.[84] Boron carbide is one of the hardest yet lightest materials, and is an excellent choice as a material for the bullet-striking face-hard armour panel. The hot-pressing technology can provide the highest density in boron carbide and thus is suitable for ballistic application. The hot-pressed boron carbide technology was transferred to M/s Bhukhanvala Industries Ltd., which supplies the boron carbide tiles not only to Indian institutes and industries but also to export them globally.

Similarly, BARC has developed technology for the large-scale production of carbon nanotubes (CNT) at an affordable price.[85] CNT is an excellent material that has found applications across various research fields. The UHMWPE-CNT composite developed by BARC is capable of absorbing higher shock energy by virtue of its high tenacity and fracture toughness.

There is an initiative by NITI Aayog on 'Make in India Body Armour', which looks after the standards for Indian BPJs. While DAE is playing an important role in developing ceramic materials and polymer composites for use in BPJs, DRDO is looking after the design and test aspects. Private players are also taking an active part in absorbing the technologies developed by DAE and DRDO in addition to their own efforts in designing body armors.

Current status

The combination of boron carbide (hard material) and UHMWPE-CNT composite (tough material) has been shown highly effective in ballistic application and has been used in the *Bhabha Kavach*,[86,87] the import substitute and the lightest BPJ of India. The hexagonal and quad design of hot-pressed boron tiles has been found suitable for withstanding multiple shots of AK-47 hard steel core bullets. The back face signature or blunt trauma of Bhabha Kavach is also below 15 mm which is well within the acceptable value of 25 mm.

The *Bhabha Kavach* has been tested as per National Institute of Justice (NIJ) and Bureau of Indian Standards (BIS) standards in Government approved laboratories and it has passed all the required tests. Successful field trials have been carried out by various Forces including Central Industrial Security Force (CISF), Central Reserve Police Force (CRPF), Border Security Force (BSF), Indo-Tibetan Border Police (ITBP), and Northern Command.

The technologies for the indigenous manufacturing of boron carbide, carbon nanotube, and the final product Bhabha Kavach are matured and have been transferred to several industries. The cost of the Bhabha Kavach is nearly half of that of an imported BPJ. Bhabha Kavach is currently being used by CISF. The Transfer of Technology (ToT) holders have received orders of a few thousand Bhabha Kavach from different Forces. Instead of importing, the ToT holders of Bhabha Kavach are in a position to export BPJ.

The science behind the excellent ballistic performance of Bhabha Kavach has been explored and published in reputed journals. These publications have received very good citations and appreciation from peer researchers worldwide.

With the advent of the higher threat level of bullets, the requirement for advancement in composite materials for ballistic application has arisen. In this respect, BARC has taken up programs on the development of composite ceramics. CNT-incorporated boron carbide has shown drastic improvement in fracture toughness and flexural strength of the composite ceramic expecting remarkable ballistic performances.

Conclusion

The technologies for manufacturing ultra-high molecular weight polyethylene in the country are not mature. DAE and DRDO should aim to develop technologies for advanced materials in incubation mode along with relevant industries. During the development stage, the materials should undergo tests as per American Society for Testing and Materials (ASTM), BIS, and NIJ standards. Moreover, at the time research laboratories are developing technologies for the mass production of advanced ballistic materials, the government should draft enabling policies to ensure that the indigenously developed materials reach the user easily without much delay.

7. GLASS & CERAMICS: YTTRIA LOADED ALUMINO-SILICATE GLASS MICROSPHERE (BHABHASPHERE) FOR LIVER CANCER RADIOTHERAPY

Liver malignancies both primary and secondary are the most prevalent causes of cancer-related deaths worldwide. Selective internal radiation therapy (SIRT) is one of the most promising treatment modalities for liver carcinoma. Intrinsically 90Y-labelled glass microsphere is the most commonly used radiotherapeutic agent for SIRT. Once administered in the hepatic artery, the microspheres preferentially lodge in the malignant hepatic cells, and the dose is deposited from 90Y [T½ = 64.1 h, Eβ(max) = 2.28 MeV] without damaging nearby healthy tissues (average penetration length of beta radiation from 90Y is 2.5mm). 90Y-labeled glass (YAS) microsphere, commercially known as Therasphere(R), is approved by the US FDA for the treatment of liver cancer and is available commercially.

As per reported data, the life expectancy of a Hepatocellular carcinoma (HCC) patient is normally in the range of 2 months to 2 years, which can be enhanced from 1 to 5 years by treatment of 0.1 gms of labelled YAS glass microspheres. However, the prohibitively high cost of commercially available 90Y-labelled glass microspheres severely restricts its utility in countries like India.

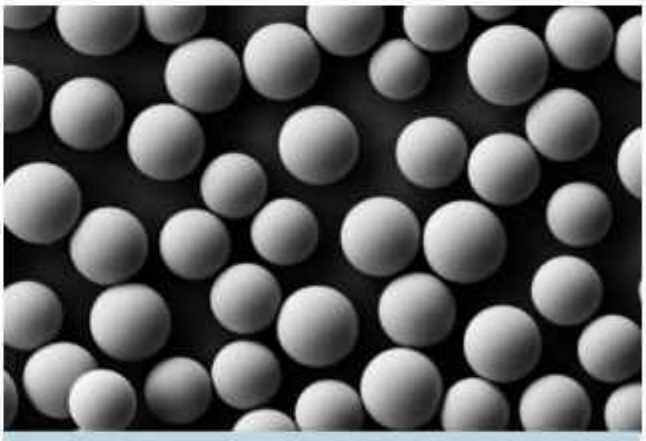


Image 34: Bhabha Sphere for Laser Cancer Radiotherapy *(Source: Bhabha Atomic Research Center inputs)*

The primary objective is the in-house development of a YAS glass microsphere and a robust methodology for the preparation of therapeutic doses of [90Y]Yttrium which is equivalent to the commercially available product (Therasphere). This will also ensure its wider availability to a larger population of patients at an affordable cost. This is achievable due to the availability of a research group in glass science, radiopharmaceutical, and research reactor with medium thermal neutron flux (Dhruva) in BARC.

Key government intervention

Initial approach to take up this topic was targeted to synthesise 89 Yttria-loaded glass microspheres of required characteristics with the availability of expertise in the field of glass science at BARC. The glass microspheres with optimised composition and controlled size (20-36µm) were synthesised successfully. Further characterisation and evaluation and implementation were carried out in collaboration with the doctors of Tata Memorial Hospital (TMH), Mumbai. Clinical trials were successful and doses were administered to patients by various hospitals on a trial basis. Technology has been ready for bulk synthesis of yttria-loaded glass microspheres.

Initial human clinical trials were carried out in TMH hospital. Preliminary investigation revealed administration of 3.4 GigaBecquerel (GBq) therapeutic doses of the developed [90Y]YAS glass microsphere formulation injected into the patient was well tolerated by the patient, as no adverse side effect of the therapeutic procedure was reported.

Current status

Formulation of ready-to-use therapeutic doses of YAS glass microsphere suitable for human clinical use in the treatment of unresectable liver cancer has been achieved. Indigenous technology for the synthesis of YAS glass microspheres with diameters ranging between 20-36 µm by flame spheroidization process has been carried out successfully. [90Y]YAS glass microspheres with adequate radionuclidic and radiochemical purity for human clinical use were produced by thermal neutron irradiation of YAS glass microspheres.

At present dose formulation with irradiated Yttria-loaded glass microsphere suitable for Liver cancer therapy is ready and available for patients. The material will be easily accessible to common people at an affordable cost through the BRIT portal. Technology is ready for bulk synthesis of controlled size [89Y]YAS glass microsphere suitable for liver cancer radiotherapy.

1.9

INDIGENOUSLY DEVELOPED AIR DEFENCE SYSTEMS

India has been working to indigenously develop defence weapons systems to neutralise threats to the security of the nation for several decades. Over the last decade, there have been several government initiatives that have supported the development of indigenous technologies that are today making their way into the armed forces to protect the nation.

Following are a few notable accomplishments of the Defence Research and Development Organization (DRDO) in creating indigenous weapon systems and contributing significantly to India's aatmanirbharta mission.

Akash Missile System

'Akash' represents India's pioneering tactical missile system, functioning as a Short Range Surface-to-Air Missile system that is designed to safeguard sensitive locations and points against aerial assaults. 'Akash' has been effectively developed, manufactured and stationed with the Indian Air Force (IAF) and Indian Army (IA) to fortify national defence by the deployment of firing units and providing round-the-clock protection of the nation. The System can engage multiple targets at once, either in Group or Autonomous mode. With built-in Electronic Counter-Counter Measures (ECCM) features, it is equipped with a state-of-the-art Radar System, missiles, launchers and other support systems working in integrated form. The entire weapon system has been configured on mobile platforms and with cross-country mobility and can be transported by air, road, and rail.

Indigenously developed Technologies regarding the Akash Missile System

- Integral Ramjet rocket propulsion and integrated aerodynamics design
- Air intakes and caps for ramjet application
- Smokeless Nitramine propellant for booster
- Multibeam 3D surveillance radar
- Multifunction phased array radar with multiple target tracking
- Multi-missile control with digital autopilot
- Distributed system-based HILS setup using RF simulation-based targets.
- High-performance electro-pneumatic actuation system
- Indigenous RF seeker technology proven with the 'Akash' system

Impact and Benefits

During the Balakot airstrike incident, the Akash Weapon System (AWS) was actively utilized. Holding significant export potential, the system is effectively used by both the Indian Army (IA) and Indian Air Force (IAF) in various concurrent war situations during routine practice firings. DRDO handed over Authority Hold Sealed Particular (AHSP) for the IA version to the Missile Systems Quality Assurance Agency (MSQAA) in December 2022.

DRDO has created a collaborative ecosystem for AWS production, with designs from DRDO laboratories, academia, and production by PSUs and Private industries. 94% of the system content is indigenous and around 90% of the subsystems are manufactured by private industries, with more than 100 MSMEs involved in the production of the weapons system generating 36,000 crore worth of orders.

Quick Reaction Surface to Air Missile System (QRSAM)

QRSAM is the first state-of-the-art Air Defence (AD) system that was developed for the Indian Army to provide a tactical land-based air defence system offering continuous mobile area Air Defence for the moving army columns. With the capability of searching and tracking command, control & communication on the move and firing on short halts, the system can engage multiple targets at ranges between 5 and 30 km.

Novelty and Exclusiveness

All the critical technologies of the weapon system are indigenously developed including a Radio Frequency Seeker, a two-way data link for mid-course guidance, an Onboard computer and inertial navigation system with Telemetry functionality, Rotary Electro-Mechanical Actuator, and four-walled active array Radar and on the move communication.
Production partners are identified concurrently in the development phase to reduce the lead time and initial prototypes are made by the identified production partners ensuring smooth Technology transfer and readiness of production documentation.
Significant features of QRSAM are:

- Target engagements in different scenarios including minimum and maximum altitude and range, Salvo firing, low RCS target, receding target and missile firing on brief halts
- India's first highly accurate laser-based end game fuze that timely triggers the firing pulse and effectively destroys targets The search and track on-the-move functionalities of both Surveillance and Multi-function radars.
- Command and communication on the move for maximum range with relay functionalities.

Impact and Benefits

- The system is mobile; with endurance for plains, semi-desert & desert terrain
- Production partners as system integrators (PSUs) are identified for the ground system as well as weapon systems
- Positive impact on indigenous MSMEs supply chain production based on demands and needs of the Indian Army.

VL-SRSAM System

The Vertical Launch – Short Range Surface to Air Missile (VL-SRSAM) weapon system, offers protection to Indian Naval Ships from diverse aerial threats. Understanding the strategic importance of such a system, the development of these weapons is prioritized across the globe. The development of the VL-SRSAM weapon system was expedited using Astra as a baseline. This is a significant achievement in bolstering India's defense capabilities. With the participation of over 100 industries, VL-SRSAM is the first Indigenous ship-borne Missile Weapon system. During this development, consistent and safe performance of the weapon system from the Indian Navy (IN) ship has been proven. DRDO is progressing on this task with full support from IN.

Very Short–Range Air Defense System (VSHORADS)

Very Short-Range Air Defense System (VSHORADS) weapon is a technologically advanced 4th generation system, superior to the 3rd generation Man Portable Air Defence System (MANPADS).

Image 35: Representative image of Very Short-Range Air Defense System (VSHORADS) weapon *(Source: DRDO inputs)*

With its **Uncooled Imaging Infrared Seeker** and high latax capability, VSHORADS have uniqueness and superiority over MANPAD. With missile maximum range of 6 km and launch altitude up to 4.5 km (AMSL), it can be fired from a Man Portable Tripod. Controlled through Aerodynamic and reaction control system, it can target fighter aircrafts, helicopters and unmanned aerial vehicles with in a specific altitude band. The advanced indigenous VSHORADS offers the benefits of cost cost-effective advanced weapon system capabilities of Intercepting manoeuvring fighter targets; operational ease, IR flare discrimination and jamming immunity.

Image 36: Representative image of the successful launch of Medium Range Surface to Air Missile (MRSAM) *(Source: DRDO inputs)*

Medium Range Surface to Air Missile (MRSAM) System- Joint Development with Israel

The Medium Range Surface to Air Missile (MRSAM) is being developed jointly with M/s Israel Aerospace Industry (IAI), Israel and will be produced for the Indian Airforce and Army Air Defence. MRSAMs are advanced, all-weather, 360° rotatable, mobile, land-based systems capable of engaging multiple targets up to 50 km, protecting against enemy air attacks.

Counter Drone System Technology

To mitigate and negate the emerging threats of Drones or Unmanned Aerial Vehicles (UAV), a counter-drone System for detection, deterrence and destruction has been developed to neutralize drone threats. Considering the unique nature of drones in terms of speed, size, hovering capability and resemblance to birds, no sensor system in standalone mode will be able to provide sufficient capability to guarantee a reliable and effective defence against threats from drones. Therefore, a system with a mix of detection capabilities, including microwave emission and reflection, infrared, and visible light, is needed for drone detection.

The Anti Drone System (code-named D4) uses multiple sensors to detect, track and identify airborne drones with information transfer for the mitigated actions. The Counter Drone System from DRDO is developed indigenously and consists of the following components:

- Drone detection and tracking Radar
- Day and night camera with laser ranging for detection and identification
- RF channel detection, Direction finding & Jamming system (Soft Kill)
- GPS Jamming/ Spoofing System (Soft Kill)
- Laser Directed Energy Weapon System (Hard Kill)
- Integrated Command & Control Centre (C3)

Impact and Benefits

The Counter Drone System, evaluated by three services and various MoD and MHA security agencies, has received production orders from all three services.

The system has been deployed for VVIP protection duties during Republic Day and Independence Day celebrations. Prototypes for one vehicle-based and one ground-based set-up have been prepared and evaluated by DRDO. The D4 system is being exported to Armenia and other export enquiries are being discussed.

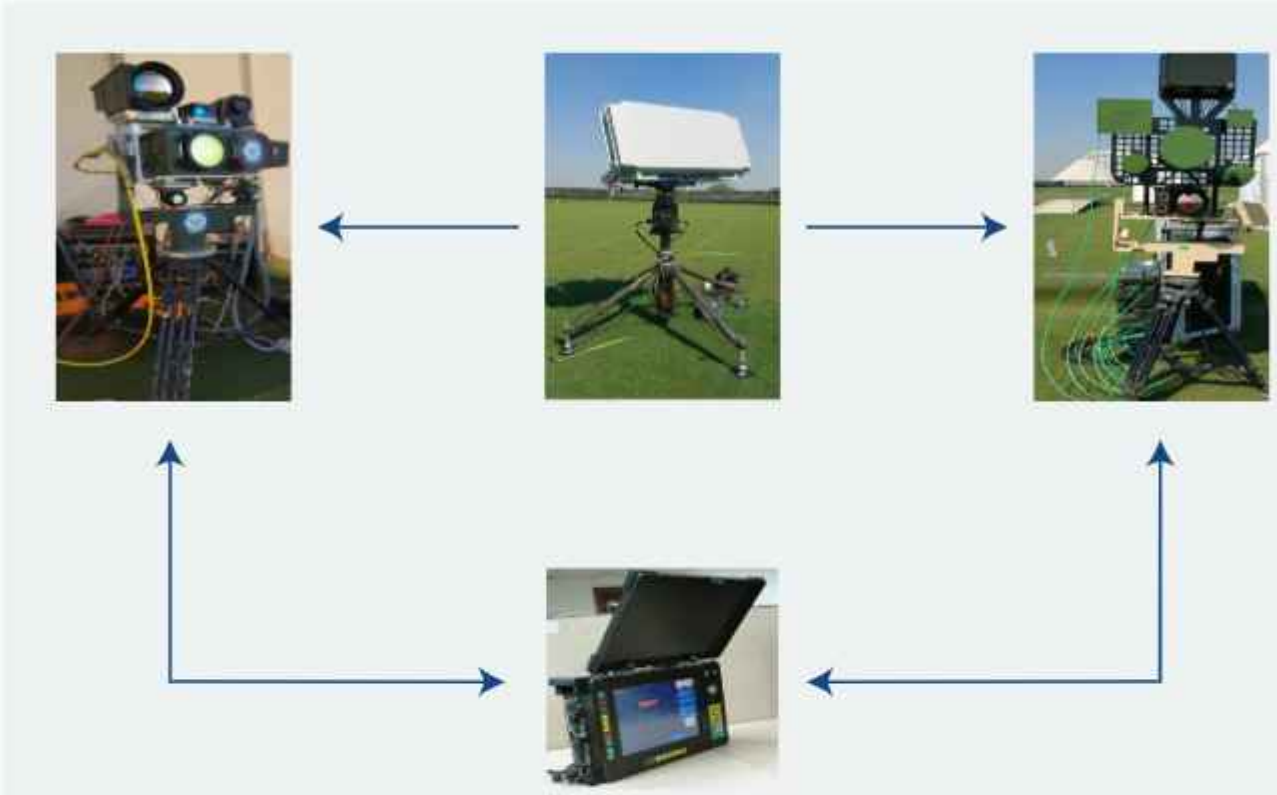


Figure 7: Counter Drone System *(Source: DRDO Inputs)*

2

ENERGY

Image licensed from freepik.com

Energy independence is an important objective for nations worldwide, as it is the cornerstone for sustainable economic and developmental progress. S&T plays an important role in this field. From new and improved methods and technologies, for accessing non-renewable sources of energy such as coal and oil & natural gas, to the development of technologies for harnessing renewable energy sources, S&T plays a crucial role. With sustainability and environmental concerns coming to the fore, there is more need now than ever to push our scientific and technological abilities to deliver on the promise of clean energy independence for India.

The Hon'ble Prime Minister of India in his 75th Independence Day speech has mentioned that India will have to pledge to become energy independent before its 100 years of Independence[88] and the GoI has made energy self-sufficiency a major goal for the nation. India is a signatory to the Paris Agreement under the United Nations Framework Convention on Climate Change (UNFCCC). Under its updated Nationally Determined Contribution (NDC), India is now committed to reduce GDP Emissions intensity by 45% by 2030, from 2005 level and achieve approximately 50% cumulative electric power installed capacity from non-fossil fuel-based energy resources by 2030.[89] India has also committed to attaining Net Zero Emissions by 2070.[90]

Reports suggest that India could become energy independent by 2047[91] with sufficient investments in developing and deploying renewable energy sources. S&T innovations and technological advancements will pave the way to delivering on this potential.

India's National Biofuel Policy 2018[92] aimed to reduce fossil fuel dependence, boost rural economy, and enhance environmental sustainability through a waste-to-wealth approach. It targeted ambitious blending goals, encouraged investments, and promoted technological advancements for a greener energy ecosystem while supporting India's environmental commitment. More importantly, it paved the way for a number of policy interventions which will be elaborated subsequently.

The GoI is also promoting wind power and has notified the "National Offshore Wind Energy Policy" in 2015. There are also programs in development to support implementation of offshore wind energy projects in coastal states. Other important government programs and schemes in the area of renewable energy include the Central Public Sector Undertaking (CPSU) Scheme which aims at setting up 12,000 MegaWatt (MW) grid-connected Solar Photovoltaic (PV) power projects by government producers, using domestically manufactured Solar PV cells; the Pradhan Mantri Kisan Urja Suraksha evam Utthaan Mahabhiyan (PM Kusum) which promotes small Grid Connected Solar Energy Power Plants, solar-powered agricultural pumps, and solarisation of existing grid-connected agricultural pumps; the Renewable Energy – Research and Technology Development (RE-RTD) Scheme which aims to support R&D projects for technology development, indigenisation, increase the share of RE in the energy mix, enhance industry competitiveness, and strengthen the MNRE's autonomous institutions; Green Energy Corridor (GEC) to create an intrastate transmission system for renewable energy projects and the PLI Scheme for National Programme on High-Efficiency Solar PV Modules to achieve Gigawatt (GW) scale indigenous solar manufacturing.

These and investments in electric vehicles, National Electric Mobility Mission, National Biogas, and Manure Management Programme,[93] investments in energy storage technologies such as batteries, etc., and many others are a testament to the importance of energy independence to the GoI.

Five efforts in this space are discussed in this report, the National Green Hydrogen Mission, National Bioenergy Programme, National Coal Gasification Mission, and Ultra Mega Solar Power Projects, and nuclear power as a few examples of specific fields in which the GoI has made efforts that are bearing fruits, and putting the nation to the course to sustainable energy independence.

2.1

NATIONAL GREEN HYDROGEN MISSION

FACTSHEET[94] [95]

Year of Union Cabinet Approval	2022
Nodal Agency	Ministry of New and Renewable Energy
Financial Outlay	Initial outlay- INR 19,744 crores. Breakdown is below. • INR 17,490 crores for the Strategic Interventions for Green Hydrogen Transition (SIGHT) programme • INR 1,466 crores for pilot projects • INR 400 crores for R&D • INR 388 crores towards other Mission components
Key Objectives	• Making India a leading producer and supplier of Green Hydrogen in the world • Creation of export opportunities for Green Hydrogen and its derivatives • Reduction in dependence on imported fossil fuels and feedstock • Development of indigenous manufacturing capabilities • Attracting investment and business opportunities for the industry • Creating opportunities for employment and economic development • Supporting R&D projects
Expected Outcomes by 2030	• Development of green hydrogen production capacity of at least 5 Million Metric Tonne (MMT) per annum with an associated renewable energy capacity addition of about 125 GW in the country • Over INR 8 lakh crores in total investments • Creation of over 6 lakh jobs • Cumulative reduction in fossil fuel imports over INR 1 lakh crores • Abatement of nearly 50 MMT of annual greenhouse gas emissions
Industrial Application	• Transportation • Power • Chemicals • Heavy Metals • Industries such as Paper, Cement,Aluminium, Food, Glass

Image 37: Components (Production, Storage, Transportation and Application) *(Source: FAST India)*

The National Green Hydrogen Mission in India represents an ambitious step towards achieving a sustainable and carbon-neutral future. Intending to make India a global leader in green hydrogen production and export, this mission holds immense potential for transforming the country's energy landscape. Green hydrogen, produced through electrolysis powered by renewable energy sources, offers a clean and versatile alternative to traditional fossil fuels.

During his address on India's 75th Independence Day, Prime Minister Narendra Modi unveiled the National Hydrogen Mission, to establish India as a global hub for the production and export of green hydrogen. This mission is pivotal in India's pursuit of energy self-reliance and independence. Recognising the country's heavy reliance on energy imports, which currently amount to over $160 billion annually, the government aims to address this challenge and prevent a potential doubling of imports within the next 15 years. With the approval of the National Green Hydrogen Mission by the Union Cabinet on January 4, 2022, India is poised to emerge as a leading player in the global green hydrogen sector.

"Not only will green hydrogen be the basis of green growth through green jobs, but it will also set an example for the world towards clean energy transition."

Hon'ble Prime Minister,[96] Shri Narendra Modi

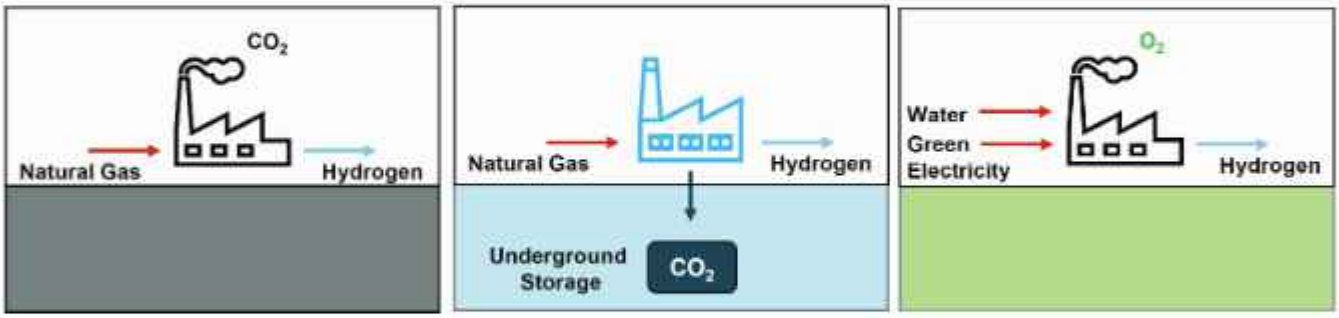
The importance of Hydrogen

Hydrogen, as an energy carrier, offers extensive possibilities for a wide range of energy and industrial applications. It possesses the advantage of long-term storage capability. However, the opportunities and challenges associated with hydrogen stem from its unique energy characteristics.

While hydrogen has a higher specific energy (energy content per unit of mass) compared to many hydrocarbon fuels, its volumetric energy density is relatively low. This necessitates the pressurisation or liquefaction of hydrogen for practical fuel usage. These properties greatly influence the value and suitability of hydrogen for different end-use scenarios.

Hydrogen production categorisation[97]

Hydrogen, despite being the most abundant element in the universe, is rarely found in its pure form and requires extraction from other compounds containing hydrogen. The degree to which hydrogen contributes to decarbonization depends on the cleanliness and sustainability of its production method. Hydrogen is categorised into different colours based on its sources and production processes.



Black/Brown/Grey Hydrogen is derived from coal or lignite gasification (black or brown) or produced through steam methane reforming of natural gas or methane (grey). These production methods are primarily carbon-intensive, resulting in significant carbon emissions.

Blue hydrogen is generated by utilising natural gas or coal gasification methods, accompanied by the implementation of carbon capture storage or carbon capture use technologies. These innovative approaches effectively mitigate carbon emissions, making blue hydrogen a cleaner alternative to traditional production methods.

Green hydrogen is produced through the process of electrolysis, which involves splitting water into hydrogen and oxygen using electricity derived from renewable energy sources. The carbon intensity of green hydrogen depends on the carbon neutrality of the electricity source. In other words, the greener the electricity fuel mix with a higher share of renewable energy, the lower the carbon footprint of the produced hydrogen.

The potential of Hydrogen in India

In the industrial sector, hydrogen has the potential to replace coal and coke in iron and steel production, which is a major source of carbon emissions globally. By decarbonising the steel manufacturing process using hydrogen, significant progress can be made toward achieving climate goals.

Moreover, hydrogen can reduce fossil fuel imports. Currently, hydrogen produced from natural gas is extensively used in the production of nitrogenous fertilisers and petrochemicals. Transitioning to green hydrogen in these sectors would enable the use of renewable energy and reduce dependence on imports.

Furthermore, hydrogen-based transport, specifically fuel cell electric vehicles (FCEVs), holds promise. FCEVs powered by hydrogen fuel have zero harmful emissions, making them an environmentally friendly option. While battery electric vehicles (BEVs) may be suitable for light passenger vehicles with shorter driving ranges, FCEVs are expected to become cost-competitive for heavy-duty vehicles like buses and trucks, which require longer trip ranges.

Hydrogen Industry Potential in India[98]

- India's annual ammonia consumption for fertiliser production is about 15 million tonnes, roughly 15% of this demand (over 2 million tonnes per annum) is currently met from imports. Mandating the use of even 1% green ammonia share is likely to save about 0.4 million standard cubic feet per day of natural gas import.
- The use of hydrogen in the steel industry could substitute imported coking coal. During 2018-19, the total demand for coking coal for the steel industry was 58.37 million tonnes. Out of this, 51.83 MT was met through imports.
- While BEVs are dependent on imported raw materials like lithium and cobalt for lithiumion batteries, the hydrogen fuel cell supply chain can be wholly indigenised, making India ***Aatmanirbhar*** in the clean transportation segment.

Current status of the Hydrogen industry in India[99]

In 2020, India's hydrogen demand was 6 million tonnes per year, and it is projected to increase by 50% by 2030. By 2050, the demand is expected to increase five-fold to 28 million tonnes, with 80% of it being green hydrogen.

Notable industrial giants such as Reliance Industries Limited, GAIL, NTPC, Indian Oil Corporation, and L&T have expressed their interest in venturing into the green hydrogen sector.

India has also set its sights on becoming a hydrogen exporter to countries like Japan, South Korea, and Europe. Several hydrogen-powered vehicles, including Tata Motors' 6-cell buses, Indian Oil Corporation's 50 hydrogen-enriched CNG buses in Delhi, and IIT Delhi's collaboration with Mahindra & Mahindra for two hydrogen-fueled internal combustion engine buses, have been developed and demonstrated with the support of the Indian government.

Future prospects

The National Green Hydrogen Mission in India offers promising prospects for the future. It seeks to position India as a global leader in green hydrogen production and export, driving energy independence and reducing carbon emissions. The mission focuses on advancing the production, storage, and utilisation of green hydrogen by integrating renewable energy sources and advanced technologies. Although the sector faces challenges in commercialisation, including production storage, transport, distribution, and end-use, the potential benefits make it a worthwhile endeavour.

The Ministry of New and Renewable Energy (MNRE) unveiled comprehensive draft R&D Roadmap for Green Hydrogen Ecosystem in India[100] which outlines the R&D priorities for manufacturing and storing Green Hydrogen. NITI Aayog, the Government of India's apex public policy think tank, has outlined a comprehensive plan with 10 actionable steps[101] to guide the National Action Plan on Green Hydrogen. This plan aims to accelerate progress and maximise the potential of green hydrogen in India's energy transition. These plans stem from the direct interventions by the MNRE to promote and strengthen the research capacity of India's renewable energy sector. Below are some highlights of the proposed plan developed by NITI Aayog:

Table 7: Highlights of NITI Aayog proposed plan

1. Develop a detailed roadmap focused on all aspects of Green Hydrogen Complementing the National Hydrogen Mission, the formulation of a national roadmap/strategy focused on green hydrogen is essential. This long-term roadmap will enhance investor confidence align the value chain, and bring together government agencies towards a unified vision.	**2. Intervene on the supply side to reduce the cost of green hydrogen to $1/kg** Government support for green hydrogen producers can include tax reductions, preferential tariffs, revenue recycling of carbon tax, low emission Power Purchase Agreements (PPAs), and discounted grid electricity for renewable energy generation, boosting its effectiveness and adoption.
3. Establish mandates and provide incentives to achieve a green hydrogen production capacity of 160 GW The government can mandate hydrogen blending in key sectors and introduce incentives like PLI for green steel, providing demand certainty and encouraging market development.	**4. Build manufacturing capacity totalling 25GW by 2030 coupled with supportive manufacturing and R&D investments** The roadmap should prioritize 25 GW electrolyser capacity by 2030 and a $1 billion R&D investment. Simplified regulations and tender preferences will boost manufacturing, with local R&D investments focusing on grand challenges and test bench infrastructure.

5. Initiate green hydrogen standards and a labelling program

Urgent measures are needed to establish standards and implement a green hydrogen labelling initiative for effective development recognition.

6. Promotion of exports of green hydrogen and green hydrogen-embedded products through a global hydrogen alliance

Pursue industrial and global energy partnerships integrating hydrogen establishing labelling and standards. Explore incentives for green ammonia and steel production to accelerate the adoption of hydrogen-based products.

7. Facilitate investment through demand aggregation and dollar-based bidding for green hydrogen

The government can support early adopters by facilitating investment through measures such as demand aggregation, accessible finance, and the establishment of a functional carbon market to provide financial certainty.

8. Encourage state-level action and policy-making related to Green Hydrogen

Encouraging states to develop their green hydrogen policies will complement national-level efforts and enhance the overall progress in the adoption of green hydrogen.

9. Encourage capacity building and skill development

Fast-track across skills the development ecosystem, encompassing government, industry, and academia, to address various aspects such as technology, business policies, and geopolitics.

10. Construct an inter-ministerial governance structure

Establish an interdisciplinary Project Management Unit (PMU) with globally trained experts and dedicate full-time resources for the effective implementation of the mission. Create an inter-ministerial mechanism to coordinate efforts across ministries and departments, ensuring seamless collaboration towards achieving the mission's targets.

Conclusion

Hydrogen plays a crucial role in India's energy transition, enhancing industrial competitiveness, reducing emissions, and improving public health. India has the potential to lead the global hydrogen economy by decarbonising hard-to-abate sectors and becoming a powerhouse of zero-carbon export products like green steel and ammonia. However, challenges such as high production costs, infrastructure development, regulations, and financing need to be addressed. Significant R&D funding, demand and supply-side incentives, revisiting standards and regulations, and financing support can accelerate the adoption of hydrogen. With the right policies and actions, India can become a global leader in the hydrogen energy ecosystem, fostering economic growth and sustainability.

2.2

NATIONAL BIOENERGY PROGRAMME

FACTSHEET[102]

Nodal Agency	Ministry of New and Renewable Energy
Implementation Period	01/04/2021 to 31/03/2026
Implementation Plan	2 Phase plan; Phase 1 approved in November 2022
Sub-schemes	• Waste-to-Energy Programme • Biomass Programme • Biogas Programme
Budget Outlay	Phase 1: INR 858 crores. Breakdown as under: • Waste-to-Energy Programme: INR 600 crores • Biomass Programme: INR 158 crores • Biogas Programme: INR 100 crores

Image 38: Bioenergy Generator
(Source: Ministry of External Affairs website)

Image 39: Sources of Biomass
(Source: Alternative Energy Tutorials)

In our quest for a cleaner and greener future, we often come across terms like "bioenergy" and "renewable resources." But what do these terms mean, and how do they impact our everyday lives?

The National Bioenergy Programme is an initiative aimed at promoting the use of bioenergy as a sustainable and renewable energy source. The programme focuses on harnessing the potential of various biomass resources such as crop residues, forest residues, agricultural waste, and energy crops for the production of biofuels, biogas, and biomass-based power generation.

By utilising these abundant resources, we can produce biofuels, biogas, and even electricity, reducing our reliance on fossil fuels and lowering harmful emissions. The beauty of bioenergy lies in its renewable nature – it can be continuously replenished, unlike finite resources like coal or oil.

Biomass refers to any organic matter derived from plants, animals, or their byproducts that can be used as a source of energy. It includes various forms of organic materials such as crop residues (like agricultural waste and stalks), wood and wood waste, animal manure, dedicated energy crops, and aquatic plants. Pellets and briquettes, a compressed and refined form of biomass, offer a reliable alternative to coal in industries for thermal applications.

Biogas is a type of renewable energy produced through the anaerobic digestion or fermentation of organic materials in the absence of oxygen. It is primarily composed of methane and carbon dioxide (CO_2), along with small amounts of other gases such as nitrogen, hydrogen, and trace elements. Biogas can be used as a fuel for heating, cooking, and electricity generation, providing a sustainable alternative to fossil fuels.

Biogas consists of approximately 55-65% methane, 35-44% carbon dioxide, and traces of other gases like hydrogen sulphide, nitrogen, and ammonia. In its raw form, without purification, biogas can be utilised as a clean **fuel for cooking, lighting, motive power, and electricity generation. It can also be blended with diesel, replacing up to 80%** in diesel engines, or used in 100% **biogas engines** for complete diesel substitution. Moreover, biogas can undergo purification to achieve up to 98% methane content, creating **Compressed Bio-Gas (CBG)**, a green and clean fuel suitable for transportation or high-pressure cylinder filling at around 250 bar.

Potential

India, renowned for its thriving agriculture sector, holds a prominent position as a leading global producer of rice, wheat, cotton, sugar, horticulture, and dairy products.[103] Additionally, the cultivation of these crops generates a significant amount of biomass, which serves as a well-established energy source, bringing forth numerous advantages. Presently, India possesses an impressive annual biomass reserve of 750 million metric tonnes, with an excess availability of 230 MMT per year. Biomass continues to play a significant role in India's energy landscape, accounting for approximately 32% of the country's overall primary energy consumption. Moreover, over 70% of the population relies on biomass as a crucial source of energy to meet their daily energy requirements.[104]

India generates substantial daily municipal solid waste of approximately 160,038.9 tonnes. This waste serves as an additional biomass source. Out of the total daily waste generated, around 95% is collected, with about 79,956.3 tonnes treated and 29,427.2 tonnes landfilled.[105] However, these landfills act as significant methane super-emitters, contributing significantly to global warming. Methane emissions account for approximately 11% of greenhouse gas emissions, trapping 80 times more heat in the atmosphere than carbon dioxide.[106] By 2031, India is projected to produce 125 million tonnes of waste annually,[107] leading to an exponential increase in methane emissions. Addressing the colossal issue of waste generation in India is of utmost importance.

The convergence of India's agricultural strength and biomass potential presents a remarkable opportunity for sustainable energy development and rural livelihood improvement. By leveraging and optimising biomass resources, India can further reduce its dependence on fossil fuels and mitigate environmental concerns. According to the International Energy Agency (IEA), implementing government policies could result in bioenergy generating around 130 million tonnes of oil equivalent (Mtoe) of useful energy by 2040. This would account for approximately 15% of India's total energy demand at that time.[108] The continued focus on harnessing the potential of biomass will not only contribute to India's energy security but also pave the way for a greener and more sustainable future for the nation and its people.

Air pollution in North India from stubble burning: A case of under-utilised potential of bio-energy

Severe air pollution in northern India centred around Delhi, has long been a matter of grave concern, and one significant contributor to this issue is stubble burning in North India. Stubble burning, a common practice among farmers to clear their fields after the harvest season, releases enormous amounts of harmful pollutants into the atmosphere, including particulate matter, carbon monoxide, and volatile organic compounds. These pollutants significantly degrade air quality and pose severe health risks to the residents of Delhi and downstream areas. According to recent data, the act of stubble burning in Delhi during the months of October and November 2022 resulted in a surge of over 25% in the PM2.5 pollution level.[109]

However, instead of burning this bio-waste, it can be effectively utilised for bioenergy production. By employing advanced technologies such as biomass gasification or anaerobic digestion, agricultural residues like stubble can be converted into clean and renewable energy sources like biogas or biofuels. This alternative approach not only addresses the problem of air pollution but also promotes sustainable energy production, reduces greenhouse gas emissions, and provides an economic incentive for farmers. By encouraging the adoption of such bioenergy solutions, we can tackle Delhi's air pollution crisis while promoting a greener and healthier environment for all.

About the National Bioenergy Programme

On November 2, 2022, the MNRE, GoI, introduced the National Bioenergy Programme. This program, spanning from FY 2021-22 to 2025-26, will be implemented in two phases. The approved Phase-I of the program has a budget allocation of INR 858 crores.

The National Bioenergy Programme encompasses various sub-schemes as under

1. **Waste to Energy Programme**: Programme on energy from urban, industrial, and agricultural wastes/residues. Supports the establishment of large-scale biogas, BioCNG, and power plants (excluding MSW to power projects). The Indian Renewable Energy Development Agency (IREDA) will be the implementing agency for the program.
2. **Biomass Programme:** Aimed at facilitating the production of briquettes and pellets for power generation and promoting non-bagasse-based cogeneration in industries.
3. **Biogas Programme:** Designed to assist in the creation of family and medium-sized biogas projects in rural areas.

Current status and achievements[110]

1. As of October 31, 2022, the Biomass Power and Cogeneration sector in India has achieved a total installed capacity of 10,205 MW. This includes:
   - 1,871.11 MW from Biomass Independent Power Producers (IPP)
   - 7,562.45 MW from Bagasse Cogeneration 772.05 MW from Non-Bagasse Cogeneration.

2. Development of a framework of incentives and Central Fiscal Assistance measures specifically tailored for biomass-based projects. The structure is as follows:
   - **Briquette/Pellet Manufacturing plants:** INR 9 Lakh per metric ton/hour manufacturing capacity (maximum CFA of INR 45 Lakhs per plant)
   - **Biomass (Non-bagasse) cogeneration projects:** INR 40 Lakhs/MW (on Installed Capacity & maximum CFA of INR 5 crores per project).

3. Promotion of installation of biogas plants through the implementation of two Central Sector Schemes under Off-Grid/distributed and decentralised Renewable Power. These schemes were valid until March 31, 2021.
   - **New National Biogas and Organic Manure Programme (NNBOMP):** This scheme facilitated the establishment of biogas plants ranging in size from 1 cubic meter to 25 m^3 per day.
   - **Biogas Power Generation (Off-grid) and Thermal energy application Programme (BPGTP):** This scheme aimed at setting up biogas plants in the size range of 30 m^3 to 2500 m^3 per day, with corresponding power generation capacities ranging from 3 kW to 250 kW using biogas or raw biogas for thermal energy or cooling applications.

4. MNRE has approved biogas plant designs that have proven their worthiness in the field. They have also established Indian standards for Biogas Plants, accessories, and appliances in collaboration with BIS. This process is ongoing. Under the NNBOMP, there are four basic models and ten approved designs of biogas plants, with detailed information available in the scheme Guidelines. All these approved designs are eligible for uniform financial subsidies and other facilities across the country.

5. Through the National Biogas and Manure Management Programme (NBMMP), approximately 5 million family-size biogas plants were installed until 2017-18. The program has since been redesigned, modified, and renamed as the New National Biogas and Organic Manure Programme, continuing from 2018-19. The NNBOMP aims to increase biogas production from small biogas plants with capacities ranging from 1 to 25 m^3.

   The objective is to set up around 250,000 biogas plants within this capacity range, generating a total of approximately 800,000 m^3 of biogas per day. The MNRE in India has also increased the Central Financial Assistance (CFA) for approved components. Additionally, 100% biogas engines are now available in smaller capacity ranges, enabling the utilisation of surplus biogas for lighting, small power, and electricity requirements from a biogas plant.

Conclusion

India's National Bioenergy Programme is a significant initiative aimed at harnessing the potential of biomass as a sustainable energy source. With a focus on promoting the installation of biogas plants, generating power from biomass, and utilising organic waste for energy production, the program addresses both energy needs and environmental concerns. The availability of financial subsidies, approved designs, and standardised guidelines contributes to the successful implementation of the program, making bioenergy a viable and accessible option for meeting India's energy demands. By leveraging bioenergy resources, India takes a significant step towards achieving its renewable energy goals and building a greener, more sustainable future.

2.3

NATIONAL COAL GASIFICATION MISSION

FACTSHEET

Year of Union Cabinet Approval	2021
Nodal Agency	Ministry of Coal
Expected Investment	INR 4,00,000 crores+[113]
Key Objective	Achieve 100 MT gasification by 2030

Coal and petroleum, and their allied products such as natural gas, and others, form the basis of not just the energy market but also of fertiliser, steel, and other important industrial products. While India's investments in renewable energy are increasing, the country is still dependent on coal and petroleum for meeting energy and industrial needs.

India is in a curious position when it comes to one of the major sources of energy today, coal. Despite being the world's second-largest coal producer and the 5th largest country in terms of coal deposits, the country is unable to meet the requirements of domestic industry and development.[111] The country has two main types of coal reserves: coking coal (used in the steel and iron industry) and non-coking coal (used in thermal power plants for electricity generation). India has large reserves of non-coking coal but lacks reserves of coking coal for industrial purposes which are then imported. India also depends on imports of chemicals such as urea and ammonia, which are by-products of the petroleum industry and important inputs for the fertiliser industry.

Environmental concerns and international emission commitments also mean that demand for cleaner ways to burn fuel is increasing. Coal gasification is a solution to both these challenges. It can be utilised in energy-efficient fuel cell technology and is a precursor to modern hydrogen production, accounting for 20% of today's world hydrogen production. Considering the country's import dependence on oil and gas, coal (used for gasification) can be a better substitute for these imported fuels.

Coal gasification is an oxidation process that converts coal into syngas which is a combination of carbon monoxide and hydrogen. Syngas can be used to produce Gaseous Fuels such as Hydrogen, Substitute Natural Gas (SNG or Methane), Di-Methyl Ether (DME), Liquid Fuels such as Methanol, Ethanol, Synthetic diesel, and Chemical and Petrochemicals like Methanol derivatives, Olefins, Propylene, Mono-Ethylene Glycol (MEG), nitrogenous fertilisers including Ammonia, DRI, Industrial Chemicals. Hydrogen produced from Syngas will also help in meeting the energy needs of the country.[112]

Figure 8: Coal Characterization Matrix for potential Mapping of high ash Indian coals
(Source: Ministry of Coal website)

Given the strategic importance of developing coal gasification, the Government of India announced a National Coal Gasification Mission, with a target to gasify 100 MT of coal by 2030.[113]

The Ministry of Coal has chalked out an implementation strategy for the Mission which include:

- Gasification potential mapping of entire coalfields.
- Setting up commercial scale plants for various feedstocks based on available gasification technologies.
- R&D efforts and completing pilot scale and demonstration scale studies in developing technologies suited for Indian coal.
- Developing a policy framework for making available coal to proposed projects to be set up both in the public and private sectors.
- Providing policy support for ensuring the financial viability of projects.
- Coordinated approach with all stakeholders including Ministries for establishing the entire value chain.

The GoI has also brought certain reforms and policies to provide impetus and support to the mission. To ensure 100 MT Coal Gasification by 2030, the Government is ensuring the availability of coal for these gasification projects by creating a separate auction window under the Non-Regulated Sector (NRS) sector and also providing a 50% concession on revenue share in coal blocks allocated under commercial mining. The Ministry of Coal has formed a new coal-linkage policy for coal gasification projects and a policy reform to consider the production of Syn-Gas from coal gasification as a subsector of the NRS has been enacted. A policy for concessions of 50% in revenue share for commercial auction of coal blocks has also been introduced. Finally, a scheme for financial assistance for the surface coal gasification projects is under preparation in consultation with different stakeholders.

To set up initial projects, 4 CPSUs have been asked to formulate joint ventures to take up these projects. It is expected that the expertise of PSUs in Mining, Gasification technology, and distribution network of final products from these projects will help in dealing with challenges.[114]

An important aspect of the Mission is the thrust on R&D for developing indigenous gasification technology that is suitable for Indian coal, with its high ash content. Several efforts are being made for this across the country namely:

- The development of indigenous coal gasification technology has been supported by NITI Aayog and DST at IISC Bengaluru and Thermax Pune.
- CSIR is funding a project at CIMFR Dhanbad for the development of coal gasification technology at a pilot scale. Pilot-scale project with a methanol generation capacity of 0.25 metric tons per day has been initiated by NITI Aayog and funded by the DST under Clean Energy Research Initiative in Hyderabad.
- In addition to the above M/s Bharat Heavy Electrical Limited (BHEL) has also developed an indigenous gasification technology and a pilot Coal to Methanol plant successfully has been demonstrated at BHEL R&D, Hyderabad.

Image 40: BHEL developed Coal Gasification facility *(Source: Bharat Heavy Electricals, Twitter)*

Coal gasification is an opportunity for the country to meet the need to be energy sufficient by 2047 and will require the close collaboration of researchers, industry, and government to make it a reality for the security of our future generations.

2.4

DEVELOPMENT OF SOLAR PARKS AND ULTRA MEGA SOLAR POWER PROJECTS

Image 41: Solar Park *(Source: Image licensed from freepik.com)*

Solar Parks are large plots of land equipped with the necessary infrastructure and approvals for solar project installations. India's Ultra Mega Solar Power Projects (UMSPPs) represent a pioneering effort in the country's quest for sustainable and clean energy sources. As one of the largest solar power initiatives globally, the UMSPPs have positioned India at the forefront of the global renewable energy revolution. These ambitious projects are transforming India's energy landscape, harnessing the power of the sun to drive economic growth while mitigating the impacts of climate change.

Aligned with its commitment to the UNFCCC through its intended NDC, India aims to decrease GDP emissions intensity by 45% by 2030 (from the 2005 level) and achieve approximately 50% cumulative installed capacity of non-fossil fuel based energy resources in the electric power sector by 2030.[15] The UMSPPs are crucial in attaining these targets outlined in the National Action Plan on Climate Change (NAPCC).

About the scheme[116]

The "Development of Solar Parks and Ultra Mega Solar Power Projects" scheme was initiated on December 12, 2014. While typically the capacity of Solar Parks considered for this scheme is 500 MW or more, smaller parks (up to 20 MW) are considered in regions with limited nonagricultural land availability. Approximately 4 to 5 acres of land per MW are required for Solar Park setup.

The UMSPPs, implemented through a collaborative effort between the government, Solar Energy Corporation of India (SECI), and private developers, have facilitated the rapid deployment of large-scale solar power parks nationwide. These solar power parks, such as the Pavagada Solar Park in Karnataka and the Rewa Solar Park in Madhya Pradesh, are redefining the renewable energy landscape in India. They showcase the success of competitive bidding processes that have driven down tariffs and made solar power economically viable. Additionally, these projects have stimulated local economies by creating job opportunities and fostering technological innovation in the solar energy sector.

Under this scheme, the Ministry provides Central Financial Assistance (CFA) of up to INR 25 lakhs per Solar Park to prepare detailed project reports. Additionally, on achieving the prescribed milestones, a CFA of up to INR 20.00 lakh per MW or 30% of the project cost, including grid-connectivity expenses, is granted, whichever is lower. The total Central Grants approved for the scheme amount to INR 8,100 crores.

The implementation of the scheme and the management of funds are handled by the SECI and the Indian Renewable Energy Development Agency (IREDA) on behalf of the GoI.

FACTSHEET

Scheme	Development of Solar Parks and Ultra Mega Solar Power Projects
Year of Union Cabinet Approval	12th December 2014
Nodal Agency	Ministry of New & Renewable Energy
Objective	Utilise India's high Solar Energy potential to set up Solar Power projects across the country through a collaborative effort comprising SECI, State governments, and private sector developers.
Current Status[117]	• GoI has approved 57 Solar Parks with an aggregate capacity of 39.28 GW, as of 28th February 2023. • 9 parks are fully complete, and 8 parks are partially complete. • The cumulative capacity of 10,117 MW commissioned.
Key Achievements	• Exponential growth of India's Solar Energy Capacity from 3,773 MW in 2014 to 63,146 MW in 2022.[118] • Bhadla Solar Park in Rajasthan with an installed capacity of 2,245 MW is the world's largest solar park as of 2023.

Key achievements

REWA ULTRA MEGA SOLAR PLANT

Image 42: Rewa Ultra Mega Solar Plant
(Source: RUMS Official website)

The Rewa Ultra Mega Solar (RUMS) plant, located in the Rewa district of Madhya Pradesh, is one of the country's most significant solar power projects. It is a joint venture under the name Rewa Ultra Mega Solar Limited (RUMSL) between the SECI and Madhya Pradesh Urja Vikas Nigam Limited (MPUVNL). The plant has a total installed capacity of 750 MW and is spread across 1,590 acres. It consists of three solar power generating units, each with a capacity of 250 MW run by Mahindra Renewables, Acme Solar, and Solenergi.

One of the notable features of the RUMS plant is its innovative tariff structure. It achieved a record-low tariff of ₹2.97 per kilowatt-hour (kWh) for the electricity generated, making it one of India's cheapest solar power projects. This low tariff was made possible through competitive bidding and a 25-year power purchase agreement with the Delhi Metro Rail Corporation (DMRC), the Railways Energy Management Company Limited (REMCL), and the Uttar Pradesh Power Corporation Limited (UPPCL).

Key features[119]

- Around 24% of the park's energy production is supplied to the Delhi Metro Rail Corporation, fulfilling a substantial 60%[120] of the daytime electricity demand of the Delhi Metro.
- It was the first solar project in the country to break the grid parity barrier (which occurs when an alternative energy source can generate power at a levelized cost of electricity (LCOE) that is less than or equal to the price of power from the electricity grid).
- This project will reduce carbon emissions equivalent to approx. 15 lakh tons of CO_2 per year.
- It was honoured with the World Bank Group's President Award.
- The project's achievements were acknowledged in the Prime Minister's Book of Innovation in 2017.

PAVAGADA SOLAR PARK

Image 43: Pavagada Solar Park
(Source: Tumkur District website)

The Pavagada Solar Park, located in the Tumkur district of Karnataka, is the third largest solar park in the world. Spread over a vast area of approximately 13,000 acres, the park has a remarkable installed capacity of 2,050 MW. It was developed as a joint venture between the Karnataka Solar Power Development Corporation Limited (KSPDCL) and the SECI.

The park comprises numerous solar power projects set up by different developers, including prominent names like Adani Green Energy, Tata Power, and Fortum. One of the notable features of the Pavagada Solar Park is its strategic location in a semi-arid region, which receives ample sunshine throughout the year. Coupled with the fact that the region has been declared drought-hit by the Karnataka Government 54 times in the past six decades, the geographical advantage enables the park to generate a substantial amount of solar power, contributing significantly to Karnataka's renewable energy capacity.

Key features

- The park generates around 4.5 billion units of solar energy per annum and thereby helps in abating CO_2 emissions to the tune of 3.6 million tons annually.[121]
- KSPDCL follows a "plug and play" model, where it procures and develops land parcels specifically for solar power generation. These blocks of land are equipped with all the necessary government approvals and infrastructure and are then leased to solar power developers (SPDs) through auction processes.[122]
- Instead of traditional land acquisition or transfer, farmers were allowed to lease out their land for 25-35 years. This model benefitted farmers who had experienced low crop yields in recent years due to inadequate rainfall. Farmers earn approximately INR 21,000 per acre per year by participating in the land lease model while retaining ownership of their land.[123]

Conclusion

India's achievements in UMSPPs have been remarkable and are important in the country's renewable energy landscape. With its vast solar resources and ambitious targets under the NAPCC, India has demonstrated a strong commitment to harnessing solar power to meet its energy demands while reducing its carbon footprint.

The projects have expanded India's renewable energy capacity and fostered economic growth, job creation, and technology development in the solar sector. The successful implementation of the UMSPPs has attracted domestic and international investments, driving innovation and cost reduction in solar power generation.

Looking ahead, India's future plans in the UMSPPs focus on further expanding solar power capacity, improving efficiency, and implementing advanced technologies. These projects have transformed India's energy landscape and inspired other nations to embrace solar power as a viable solution for their own energy needs.

2.5

INDIA'S NUCLEAR POWER PROGRAM: FROM SCIENCE TO SELF-RELIANCE

India's nuclear power program has over the decades knit together the worlds of indigenous scientific research, technology development, and reliable and safe public service delivery. Initiated under the watch of stalwarts such as Dr. Homi Bhabha and Dr. Vikram Sarabhai in the early years after India's Independence, the sector's continued growth is a matter of pride for the entire nation. Its achievements in recent years are providing it a platform for an even bigger role in future of the Indian power sector, supporting the twin national objectives of energy independence and Net Zero carbon emissions by 2070.

India's installed nuclear capacity has increased from 4,780 MW in 2013-2014 to 7480 MegaWatt (MW) in December 2023. Annual electricity generation from nuclear power plants has increased from 35.3TWh in 2013-14 to 46.9TWh in 2022-23[124], reflecting avoided emissions of approximately 353 million tonnes of CO_2 equivalent into the environment over the past decade.

A strong foundation in nuclear power research

India's nuclear energy journey has been a stellar example of indigenous capacity building, over decades. An ambitious plan for indigenously operating and developing nuclear plants for civilian purposes, which would come to be known as the *Three-stage Nuclear Power Program*, provided guidance for successive developments and increasing self-reliance, over the decades. Uranium, the most commonly used nuclear fission fuel, is in low supply in India. The country is almost entirely import-dependent for uranium, having imported 2,000 Metric Tonnes (MTU) of uranium in different forms from Canada and Kazakhstan in 2020-2021[125]. However, India holds one of the world's largest known thorium reserves[126], another radioactive element that can be used as a source of energy, found as naturally available mineral monazite in predominantly coastal areas. The conversion of Thorium into Uranium-233 is at the heart of our three-stage nuclear power program.

The three-stage program has a closed fuel cycle policy. The spent nuclear fuel is not discarded as waste instead it is processed and reused as fuel for reactors in the next stage of the program.

STAGE 1: Natural uranium-fuelled Pressurized Heavy Water Reactors (PHWR) and Light Water Reactors (LWRs) would primarily produce electricity. The Plutonium (PU^{238}) and depleted Uranium are obtained as by-products.

STAGE 2: Fast Breeder Reactors (FBRs) utilise plutonium-based fuel, generate electricitv and convert Thorium (Th^{232}) to fissile uranium (U^{233}). Breeder reactors produce more fuel than they consume and this allows the generation of fuel for the next stage.

STAGE 3: Advanced nuclear power systems for utilization of Thorium which in itself is not a fissile material, but the reaction would be based on a self-sustaining reaction of Thorium and Uranium (U^{233}).

Stage-wise Articulation of India's Three-stage Nuclear Program[27]

Technological achievements in the nuclear program

India has had remarkable achievements in the entire spectrum of activities related to the nuclear power programme including design, construction, operation, renovation, modernization, and rapid expansion of nuclear power. Indian scientists, engineers, and industry have showcased their technical skills, and the nation's regulatory capacity has been demonstrated through the standards and reviews set by the Atomic Energy Regulatory Board. This has been evident in the development of both Pressurised Heavy Water Reactors (PHWRs) and Light Water Reactors (LWRs). The involvement of Indian industry in the supply of equipment and execution has also been an important area of progress over the last decade.

PHWR capacity in the country has more than doubled thanks to indigenous efforts. The latest achievement is the successful commissioning and operation in 2023 of the indigenously-designed PHWR Unit 4 of the Kakrapar Atomic Power Project (KAPP 4), which is rated at 700 MW. The preceding units, namely KAPP 3 (700 MW) and KAPP 1&2 (220 MW), were already operational. KAPP 4 is second in a series of 16 indigenously designed PHWRs that are being set up in the country[28].

Image 44: Kakrapar Nuclear Power Plant *(Source: DAE inputs)*

The present installed capacity of 7,480 MW is expected to increase to 21,980 MW by 2031-32, which includes the 500 MW Prototype Fast Breeder Reactor (PFBR) under commissioning at Kalpakkam, in Tamil Nadu as a part of Stage 2 of the Nuclear Power Program. The Fast Breeder Test Reactor (FBTR) commissioned in 1985 at Kalpakkam, provided the experience required to develop the PFBR. An extensive manufacturing technology development program has supported the enhancement of industrial capability for manufacturing components required for such reactors and all components of the PFBR have been manufactured by Indian industry[129].

Image 45: Prototype Fast Breeder Reactor (PFBR) of BHAVINI *(Source: DAE inputs)*

An important demonstration of domestic nuclear technological prowess is that the current fleet of Nuclear Power Plants has demonstrated some outstanding performance with continuous operation of 962 days by Kaiga- 1 unit, setting a world record for continuous operation of nuclear power reactors. In addition, some of our PHWRs have operated continuously 43 times over a period of one year, which includes more than 700 days of continuous operation on five occasions[130].

The safety of nuclear power is a paramount consideration, and Indian nuclear power plants operate under stringent standards set by the National Atomic Energy Board. An admirable achievement is that the safety record of Indian nuclear power plants has been impeccable so far, with no accident or instance of release of radioactivity beyond stipulated limits in over 53 years of nuclear power plant operation.

With Stage 3 of the nuclear program in the offing, the Department of Atomic Energy through its research centres such as the Bhabha Atomic Research Center is designing advanced reactors, and researching technologies for thorium utilization. India has had engineering scale expertise on the thorium fuel cycle and is working on industrial and commercial scale thorium utilization[131]. India is pursuing R&D on multiple avenues for large-scale thorium utilization through the development of reactors[132] such as Advanced Heavy Water Reactors (AHWR), High-Temperature Reactors (HTR) and Molten Salt Breeder Reactors (MSBR) as well as relevant technologies associated with these systems.

Indigenous capability development for nuclear power has also been developed during the last several decades. Specialised R&D capabilities, specialised infrastructure to produce fuel, heavy water, reactor control,

instrumentation, and technologies among others have been developed within the country. Indian industry is also an important stakeholder in the nuclear power story of the nation, with increasing involvement in constructing newer generations of reactors. Indian industry has also won contracts for civilian construction in a Bangladesh project[133].

With the Indo-US Nuclear Deal and the Nuclear Supplier Group waiver for India in 2008, avenues for exploration of new opportunities for the entire three-stage program have opened up. India has agreements with nations such as the Russian Federation, France and the United States, and is also providing support to Bangladesh for a nuclear power plant.

Conclusion

The story of India's nuclear program has been one of perseverance, scientific expertise, and commitment to making the nation energy independent through **Aatmanirbharta or self-reliance**[134].

India's path to nuclear energy self-reliance has arguably travelled the less-trodden path by focusing on thorium as fuel, rather than relying only on imported uranium. The capabilities that India has built in nuclear power, technical, infrastructurally, as well as in capacity are the foundation to an energy secure nation, and a contribution to other industrial and R&D sectors.

3

EXPLORATION

Curiosity and the impulse to explore are hallmarks of human behaviour. Through discovery and exploration, we learn more about the environment around us, and more about us as well.

Some of the greatest global technological advances have been the product of exploratory or fundamental research, where the quest to learn more about the world around us has resulted in surprising inventions and technologies. Very often the outcome of the research was not known at the time. History has many examples of this. Einstein's Theory of Relativity, even before it had been proved, had applications in the functioning of GPS, a technology that we take for granted today.

What do high-speed internet and quantum physics have in common? Lasers. Lasers, when first developed by Theodore S. Maiman, based on work done by Max Planck and later expanded by Albert Einstein, were described as a "solution without a problem'.[135] Today, lasers are a foundational technology in almost every field of technology and science from biotechnology, telecommunications, and space, among many others.

Another example is polymerase chain reaction (PCR) tests. These came into the public eye and vocabulary during the pandemic, as the gold standard for COVID-19 diagnosis, and would not have been a reality, if researchers had not asked a fundamental research question: how do bacteria in hot springs replicate themselves? Essentially, an enzyme, Taq polymerase found in these bacteria, allowed the development of the PCR.

The seeming disconnect between the scientific question and its application to everyday life today is apparent, but this is how scientific research functions.

Advancements in fundamental sciences lay the foundation for the development of new technologies and treatments, many of which were not known or even dreamt of at the time. Advances in one field expand into other fields in unexpected and often hugely impactful ways. Lasers, an invention from quantum mechanics, found use less than a year later in medicine when the first laser was used to destroy a tumour in the eye of a patient.[135] An obvious endpoint or result is not necessary for scientific research and curiosity.

India has consistently invested in and funded basic research across many fields of science. The Large Hadron Collider (LHC), Square Kilometre Array (SQA), and the International Thermonuclear Experimental Reactor (ITER), among many others, are just some examples of exploratory research, where India is actively participating. In this section, we discuss two recent investments in exploratory research that seek to explore the depth of the oceans and the universe itself, the Deep Ocean Mission and the newly announced LIGO.

3.1

DEEP OCEAN MISSION

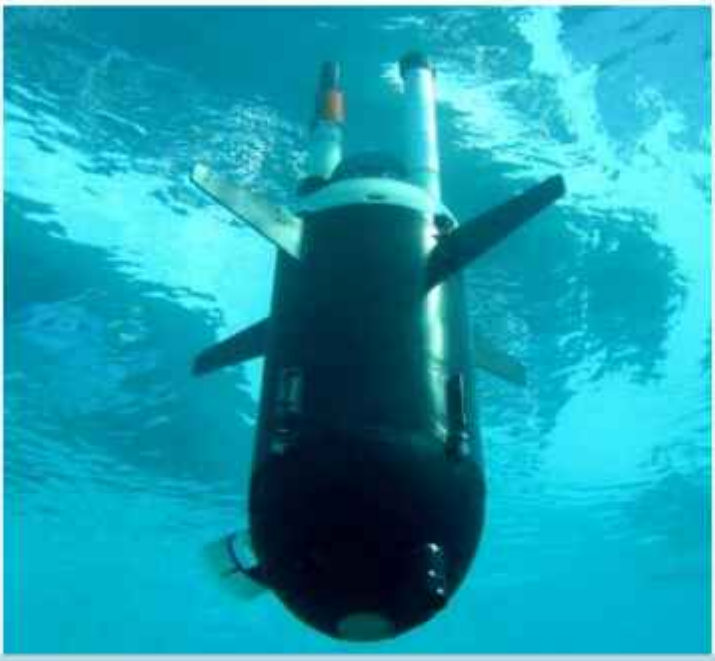


*Image 46: **Deep Ocean Mission** (Source: Office of the PSA)*

FACTSHEET

Year of Union Cabinet Approval	2021
Nodal Agency	Ministry of Earth Sciences
Financial Outlay	INR 4,077 crores over five year period
Key Achievements	• Launch of first manned Ocean Mission of India, Samudrayaan in 2022 • Indigenously designing, developing and testing of deep sea miner, manned submarine, and Deep water Autonomous Underwater Vehicle AUV and various technologies required for deep sea exploration
Key Outputs	• Better understanding of marine biodiversity • Identification and delineation of mineral zones in delineated seabeds

Image 47: Self-propelled Miner with pick up device and deployment view in NIOT-MoEs ship ORV Sagar Nidhi *(Source: Ministry of Earth Science inputs)*

WHY DEEP OCEAN MISSION?

The oceans are responsible for modulating and sustaining life on planet Earth. They are earth's largest ecosystems and help in sustaining life by absorbing about 1/4th of global carbon dioxide emissions and providing employment to small-scale fisheries, among many other benefits.[37] With global warming and plastic pollution, the ocean ecosystem is in danger. In addition, little is known about the deep seafloor and its habitats, and their role in sustaining life on earth. Exploration of the deep sea can help in building systems that can sustainably harvest the oceans for their energy, mineral resources, biodiversity, and climate forecasting without harming its ecosystem, exploration of deep sea is required. The remoteness of the deep sea makes it difficult for scientists to access and observe it. Therefore, new technologies have to be developed in order to study the ecosystem of the deep sea.

These new technologies will help in understanding marine biodiversity as well as identification and delineation of mineral zones in delineated seabeds. Advancing in deep-sea research will involve working together with other countries as well as international agencies. Under the Deep Ocean Mission, India aims to establish the infrastructure required for Advanced Marine Station for Ocean Biology and collaboration with national and international marine research institutes by 2024. Developing and deploying new technologies will help India in understanding the climate change impact in an accessible manner, i.e., through a GIS-based interactive tool on inundation maps and shoreline changes for various climate scenarios. On a national scale, it will help India to develop strategies for the protection of coastal areas for various climate change scenarios. For further research and/or commercial use, India aims to establish a deep-sea microbial repository by 2025.

Targets

The Deep Ocean Mission was introduced in 2021 and has goals for the next five years' horizon which include:

- Supporting indigenous organisations with infrastructure and equipment required for research and development,
- Enabling development and deployment of technologies for conducting deep sea research,
- Assimilating and analysing information obtained from the research to outputs usable to citizen and the nation.

Indian research organisations including the National Institute of Ocean Technology and VSCC at ISRO support the mission. In addition, the acquisition of a new multi-disciplinary oceanographic research vessel is underway. Its concept, functional design, and technical specifications are completed and bidders are being identified. The new research vessel will serve as a platform for undertaking oceanographic research in the deep ocean in line with other countries. At the present stage, the mission is focused on developing technologies required to enable deep-sea exploration. These include:

- Development and deployment of:
  - Mining system capable of operating in water depths up to 6,000 m to mine polymetallic nodules from the deep ocean
  - Deep Sea Miner, a self-propelled mining system, for Polymetallic Manganese Nodule collection and local pumping
  - 6,000 m depth-rated manned submersible
  - Shallow water personnel sphere
  - Deepwater Autonomous Underwater Vehicle AUV (Ocean Mineral Explorer – 6000 (OMe 6000)) to explore deep sea mineral resources at polymetallic manganese nodule, hydrothermal sulphides, gas hydrates, etc.
  - Hydrostatic sample transfer system
- Sea trials of shallow water manned submersible by 2024
- Deep sea qualification of Manned submersible (MATSYA 6000) by 2026.
- Construction and delivery of new multi-disciplinary Research Vessel by 2026
- Pumping system sea trials for deep sea mining in 2024 and deep-sea mining machine by 2026.

Image 48: AUV – OMe 6000 launching view from the ship Sagar Nidhi at Central Indian Ocean Basin
(Source: Ministry of Earth Science inputs)

Key achievements

- To explore the deep ocean basins, National Institute of Ocean Technology has designed a 6,000 m depth rated manned submersible capable of carrying three persons.
- The first Manned Ocean Mission "Samudrayaan" was launched on 30th October, 2021 at Chennai. With the launch of the unique ocean mission 'Samudrayaan' in October 2021, India joined the elite club of nations such as the US, Russia, Japan, France, and China to have niche technology and vehicles to carry out subsea activities.[38]
- The National Institute of Ocean Technology has successfully tested its mining system for polymetallic nodules at a depth of 5,270 m at the designated contracted area with the International Seabed Authority.
- PMN sub-systems and components have been sized and optimised for weight and power and tested in laboratory conditions before the planned tests at sea.Deep water Autonomous Underwater Vehicle AUV (Ocean Mineral Explorer – 6000 (OMe 6000)) fitted with necessary scientific payloads for deep ocean scientific research was successfully launched and recovered in the high seas safely to explore deep sea mineral resources site at polymetallic manganese nodule, hydrothermal sulphides, gas hydrates, etc apart from another search/engineering operations in deep sea with the defined path.

Conclusion

The new technologies being developed and planned for the near future by India will help in understanding marine biodiversity as well as the identification and delineation of mineral zones in delineated seabeds. Advancing in deep-sea research will involve working together with other countries as well as international agencies. Therefore, India aims to establish the infrastructure required for Advanced Marine Station for Ocean Biology and collaboration with national and international marine research institutes by 2024.

In addition, for further research and/or commercial use, India will establish a deep-sea microbial repository by 2025.

3.2

LASER INTERFEROMETER GRAVITATIONAL – WAVE OBSERVATORY

Humans have always explored. First, it was the seas and land, then the air, and then space. Now we are exploring the expanse of the universe to answer questions about the birth of the cosmos. Humankind's thirst for knowledge has been the cornerstone of our advancement as a species.

From this thirst for knowledge to understand the universe, the last half century has seen the birth of an entirely new field of universe exploration: Gravitational wave astronomy which relies on "hearing" the universe rather than "seeing" it, as traditional astronomy has. Traditional astronomy relied on using light or other waves such as X-rays to see the universe. Gravitational waves are ripples in space-time that are caused by accelerations or collisions of large masses in the universe.

Einstein's Theory of General Relativity, in 1916, had postulated that accelerating massive bodies will produce gravitational waves, or vibrations in the fabric of spacetime. However, it took 100 years, and several generations of technology to prove this theory by being able to detect gravitational waves.

On 14th September 2016, the LIGO Scientific Collaboration in the US and Virgo Collaboration in Europe announced the first confirmed observation of gravitational waves from colliding black holes.

This discovery not only validates Einstein's Theory of General Relativity but opens up immense possibilities for us to understand the nature of the universe around us.

Currently, there are 4 LIGO Interferometers in the world, two in the United States and one in Europe that are operational and within detection range for gravitational waves, and a fourth one in Japan which is underway. A minimum of 4 comparable and operational detectors is required to allow us to detect gravitational waves anywhere from the sky.[139]

India is the fifth LIGO detector and a crucial one.[140] LIGO India, which is a collaboration between the National Science Foundation (NSF) in the US and the DAE and the DST in India, will catapult the country into an elite group of nations with capabilities in this sector. LIGOIndia is a collaboration between the LIGO Laboratory—operated by Caltech and MIT and funded by the NSF—and India's Raja Ramanna Center for Advanced Technology (RRCAT), Institute for Plasma Research (IPR), Inter-University Centre for Astronomy and Astrophysics (IUCAA), and the Department of Atomic Energy Directorate of Construction Services and Estate Management (DCSEM).

Image 49: Conceptual aerial view of LIGO India
(Source: Department of Science and Technology inputs)

LIGO India received approval from the Union Cabinet in February 2016, shortly after the first discovery of gravitational waves was announced. The gravitational wave LIGO detector is an L-shaped instrument with each arm being 4 kilometres long. Preparatory work on capacity building, technology development, and component prototyping for Gravitational Wave Detectors has been carried out and the site for the detector has been announced as Hingoli district in Maharashtra, approximately 450 km from Mumbai.

Full approval of the Union Cabinet for LIGO India was given in April 2023, at an estimated cost of INR 2,600 crores. The detector is expected to be operational by 2030.

What's in it for the common man: Pushing frontiers

While the entrance of India into this field is a major achievement for fundamental research in the country, its application and impact on the everyday lives of people is perhaps harder to understand. What LIGO represents or will give the world, apart from the knowledge of the universe that we are part of, will be seen in decades to come.

However, the mere act of operationalising LIGO India, in collaboration with industry partners in the country, will push the boundaries of research capabilities that we have in the country today. Large frontier research projects propel technology development and capacity building. There will be cross-thematic benefits to India's astrophysics research, high-end technological development, and human resource development in the country.

Capacity building in cutting-edge science and engineering will mean that students/researchers will have the benefit of working on this frontier of science in India itself.

LIGO relies on quantum metrology which is an important domain of expertise for precision measurements in the future.

The lasers and optics to be used in the LIGO are at the cutting edge of technology today and this expertise will benefit indigenous capacity.

LIGO's vacuum system is one of the largest in the world and creating this capability in Indian industries will benefit other activities in accelerator development and space technology. The capacity and capability built up by Indian industries for the fabrication of large vibration-isolated, temperature-stabilised clean-rooms for the project would benefit future projects that require similar facilities for contamination controls, such as semiconductor fabrication, biotechnology, etc.

Image 50: Vacuum chambers for the 10 m arm length prototype at RRCAT
(Source: Department of Science and Technology input)

The LIGO control system is one of the most complex systems ever built and uses AI for automated interferometer alignment. This expertise would benefit other challenging projects that require multi-input, multi-output control systems with machine learning.

India's strength as a scientific and technological hub will be cemented with LIGO India and the benefits to the nation will be reaped in the years to come.

India's contribution to international scientific efforts is an extension of our national belief of *"Vasudhaiva Kutumbakam"*, or the world is one family. India has been a major contributor to the Large Hadron Collider at CERN and the International Thermonuclear Experimental Reactor (ITER) among others.

The benefits of investing in basic and foundational research may not change the course of our lives today. However, it will set the stage and trajectory for the advancement of our future generations as a lasting legacy. Investing today in knowledge for knowledge's sake may be the only way we conquer the challenges that are too big for us to solve right now.

Source: NPCI, Knowledge center, at
https://www.npci.org.in/PDF/npci/knowledge-center/UPI%20Booklet%20April%202018%20-%20Collateral.pdf

4

PUBLIC SERVICE

A central responsibility of any government towards its citizens is public service delivery. Public service delivery is the service that governments provide their citizens, either through direct delivery or by paying for it, and includes services such as education, healthcare, waste disposal, social services, and infrastructure such as roads and communications, among others.

S&T play an increasingly important role in this space. Technological innovations and advancements are key to the improved coverage and efficiency of these services, to ensure that no one is left behind.

India has witnessed the game-changing improvements that the UPI has brought to the daily lives of millions in the country. Advances in logistics planning and waste management are also changing the landscape of everyday life in the country. These three efforts are discussed in the following sections.

In the communications field, technologies related to 4G, 5G, and the National Broadband Mission are driving progress for the nation, by taking forward the country's capabilities as well as ensuring equitable access to all.

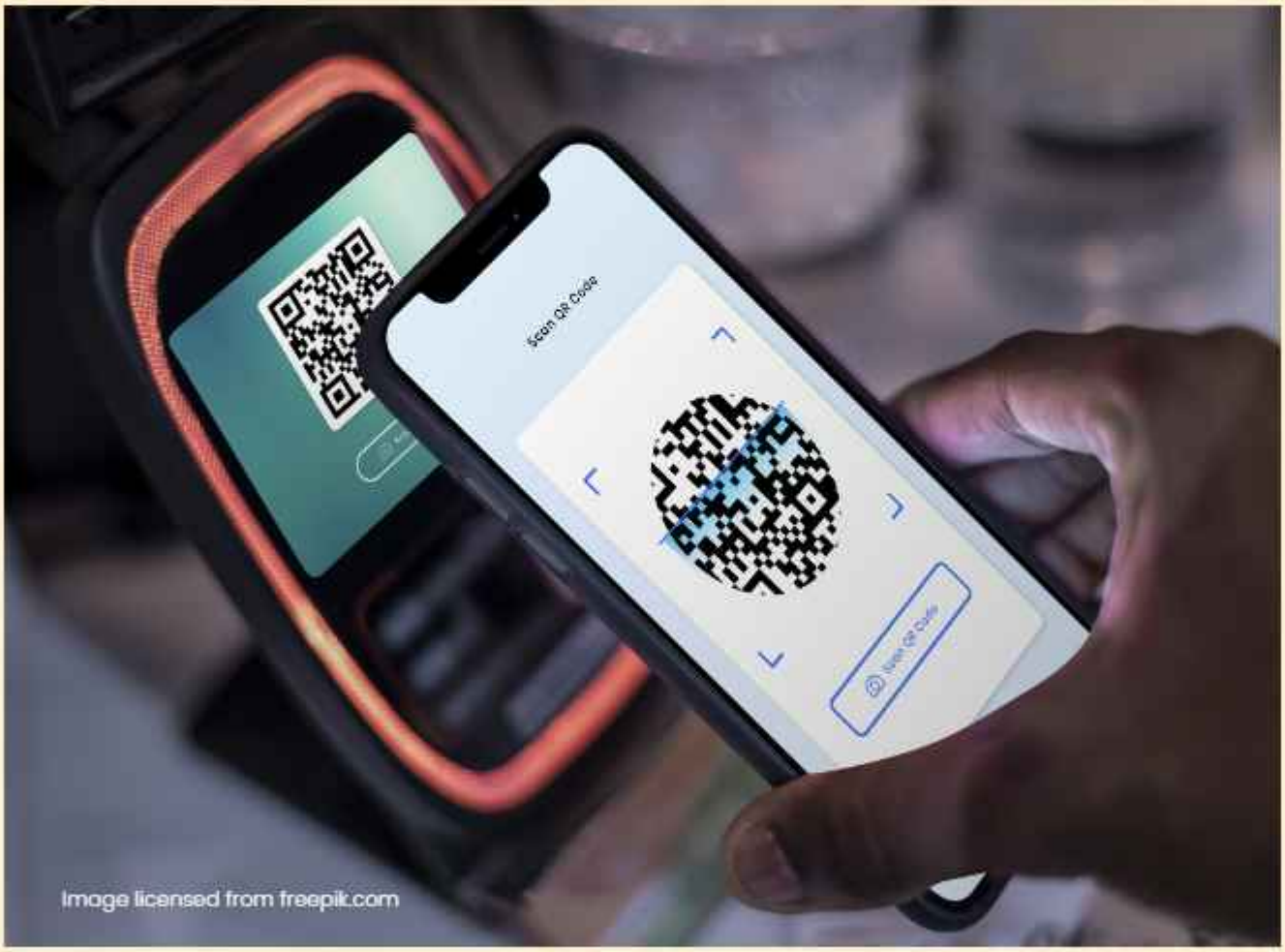


Image licensed from freepik.com

4.1 India Stack: Digital Public Infrastructure of the 21st Century

Approximately 24.5 lakh[141] digital payments, amounting to almost INR 501 crores will be made across India before you finish reading this section. In the last few years, India's digitalisation journey has been steered by the India Stack, which is a set of open Application Programming Interfaces (APIs) DPGs that aim to unlock the economic primitives of identity, data, and payments at a population scale. Its scale of adoption in India over the last decade has been extremely rapid,[142] and it has helped promote the national priorities of financial and social inclusion[143] to enable India to fully embrace the Internet age.

The Digital India campaign is an all-encompassing and transformative program. It seeks to deliver cost-effective and domestically-developed digital technology, ensuring inclusivity, bridging the digital divide, and fostering digital inclusion.

India Stack consists of three layers:[144]

- **Identity layer** gives each citizen a unique ID through Aadhaar, eKYC, and eSign.
- **Payments layer** makes payments between citizens easier through UPI, Direct Benefit Transfer (DBT) through the Aadhaar Enabled Payments System (AEPS) and the Aadhaar payments bridge.
- **Digital empowerment layer** provides data protection for citizens through services such as DigiLocker, Account Aggregator and DigiYatra.

Image 51: Foundations of India Stack *(Source: Forbes (2023), How OCEN Is Democratizing Credit Access In India)*

DPI also consists of open services such as Open Network for Digital Commerce (ONDC), CoWin, Ayushman Bharat Health Account (ABHA) , and Svamitva Yojana. ONDC is a DPI-enabled online marketplace; CoWin and Ayushman Bharat Health Account provide digitally-accessible health services; and Svamitva Yojana provides digital land records.

India Stack's transformative role in empowering citizens can be seen most clearly through the following cases.

The lives of rural Indian citizens, 64% of the country's population, have been transformed by India Stack in several ways.[145]

- With Aadhaar and eKYC, the identity layer provides a unique ID that enables access to various government services and entitlements seamlessly.
- The benefits from welfare schemes are received directly through the DBT system, making the process more efficient and reducing leakage. DBT is based on the AEPS, joining the payments and the identity layers. This enables convenient and secure transactions, eliminating the need for cash and reducing the risks associated with carrying money over long distances. Convenient digital payments for goods, services, agricultural produce, etc., fosters financial inclusion and empowerment.
- At the same time, data storage services, like DigiLocker, enable the security of important documents and certificates, especially helpful in accessing land records, educational certificates,

India's DPI provides convenience and efficiency in the everyday life of an urban professional citizen.

Aadhar and eSign's identity layer streamlines authentication processes, making it easier to avail online services like e-filing taxes, getting a passport, driving licence, and signing documents. This saves time and reduces the need for physical visits to government offices. DigiYatra makes travelling pan-India through airports easier. Similarly, the payments layer makes daily financial transactions quick and secure through UPI and AEPS. As internet-based payment systems become the norm, seamless integration of payment streams reduces the hassle of managing multiple payment platforms.

The digital empowerment layer of DigiLocker and Account Aggregator enables easy access to important personal data and financial information. This makes storing and managing documents, financial data, and investment details secure and facilitates better financial planning and decision-making.

Even as the digital payments layer has been hugely successful in both its implementation and take up, there are plenty of challenges faced by UPI, which require constantly evolving strategies to overcome. These include strengthening cybersecurity, enhancing technology infrastructure, conducting user awareness campaigns, and engaging with stakeholders. Collaboration with banks and technology partners is crucial for scalability. The Innovation and Technology Foundation at IIT Bhilai has partnered with NPCI to identify problem statements and seek solutions from researchers and innovators. Some challenges include detecting fraudulent transactions, enhancing QR-based payments' security, and developing an open-source payment confirmation system for diverse user groups.

The recently introduced ONDC has the potential to open up new opportunities for small businesses that do not have access to large aggregation and online delivery platforms. ONDC could allow such businesses to participate in government-enabled online marketplaces. This could provide businesses exposure and access to an online customer base that is critical for growth and sustainability.

CoWin has revolutionised India's access to healthtech for the average citizen. It was critical in India's journey to weather the COVID-19 pandemic. The Ayushman Bharat Health Account (Health ID) not only creates secure digital health records for citizens but also facilitates easy communication with participating healthcare providers. This enables citizens to quickly and conveniently access digital test results, prescriptions, and diagnoses from licensed medical practitioners and healthcare providers.

Svamitva Yojana, run by the Ministry of Panchayati Raj, utilises drones and Geographic Information System technologies to provide digital land and population records. This reduces land-related disputes, enables land monetisation, and empowers the average citizen through the availability of land-related information.

Unified Payments Interface

Perhaps the most popular example of digital public infrastructure is the Unified Payments Interface (UPI) and the applications that have been developed.

The Bharat Interface for Money (BHIM) App was launched in December 2016 as a mobile payment application based on UPI. It showcased the potential of UPI and was placed as a simple and easy-to-use app allowing users to make digital payments through their smartphones. The vision for a cash-independent India was fostered by NPCI along with RBI, which rallied banks and non-banks, followed by major players like PhonePe, Google Pay and Paytm joining UPI as Third Party App Providers (TPAPs). To promote acceptance of digital payments among merchants, the government subsidised P2M transactions for acquiring banks.

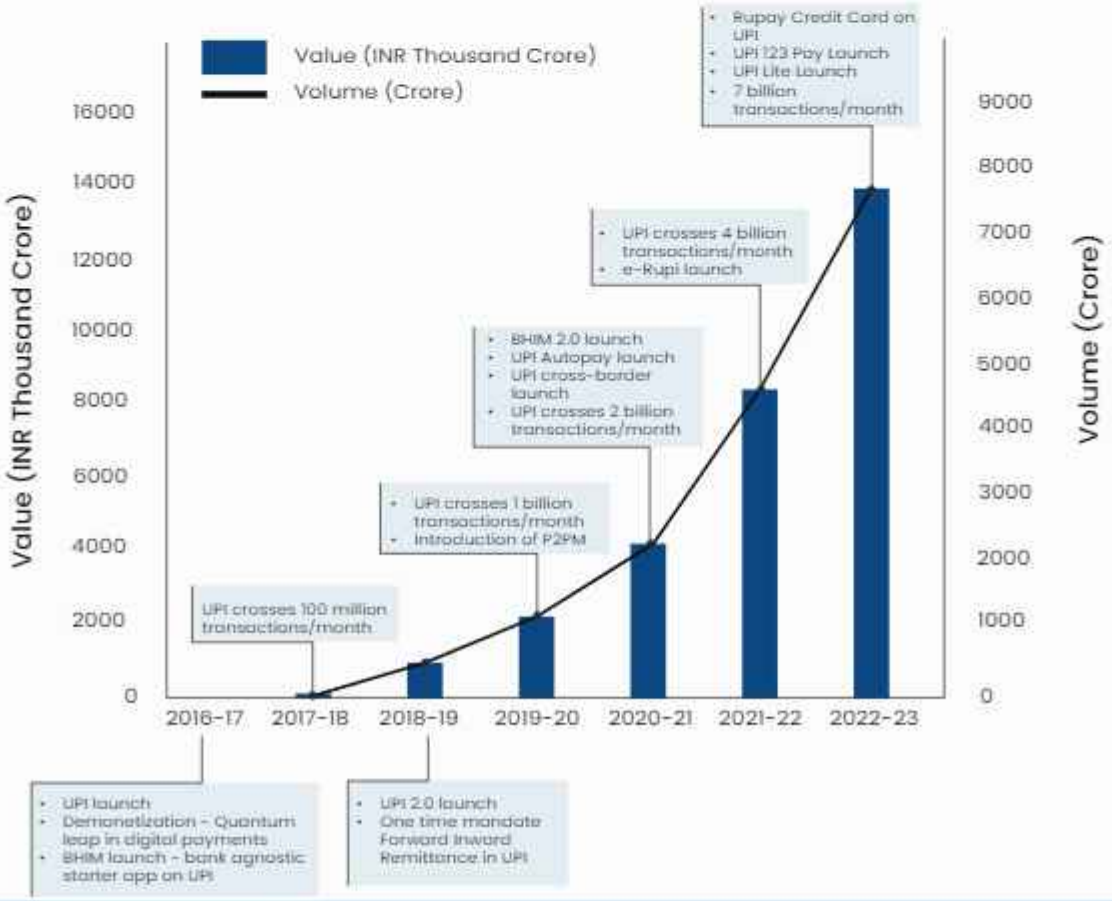


Figure 9: Growth of UPI *(Source: Department of Financial Services Inputs)*

With the larger goal of boosting financial inclusion, UPI has witnessed certain enhancements over time to increase its user accessibility and convenience. Some recent enhancements include an AI voice-enabled payment feature, linkage of RuPay Credit Card, and voucher management system to provide direct benefits of specific government schemes and offline UPI payments through UPI Lite X.

Many efforts are being made to take the UPI revolution abroad, and countries such as Singapore and the UAE have started to connect some payments to it.

More than 75% of the retail electronic payment transactions in India are through UPI. The platform currently has 300 million users, along with 50 million merchants and 500 participating banks.

UPI's transformative impact goes beyond the scope of digitising payments. It continues to champion and facilitate financial inclusion by reaching out to the unbanked and underbanked, fostering economic engagement in rural areas, and promoting financial literacy.

Conclusion

India's DPI has leveraged home-grown technological advancements to transform the lives of citizens, irrespective of their socio-economic backgrounds. The different components of India Stack provide convenience, efficiency, and empowerment and have truly democratised access to digital technology in India.

4.2 Communications

4.2.1

4G INDIA — CATCHING UP, POISED FOR A LEAD

Mobile telephony has seen rapid advances over the last few years, with most of us now able to stream videos, audio, and live meetings right to our hand-held devices while on the go, something which was science fiction till barely a decade and a half ago. The advances have been an output of technological innovation, business investments, advancements in digital user interfaces, and eager consumer adoption.

As this mobile telecommunications revolution picked up, India lost out in the race to domestically manufacture the equipment. Both handsets and mobile tower equipment were imported for decades, leading to a situation where India's electronics equipment import was almost equalling our oil imports,[146] adding to trade deficits.

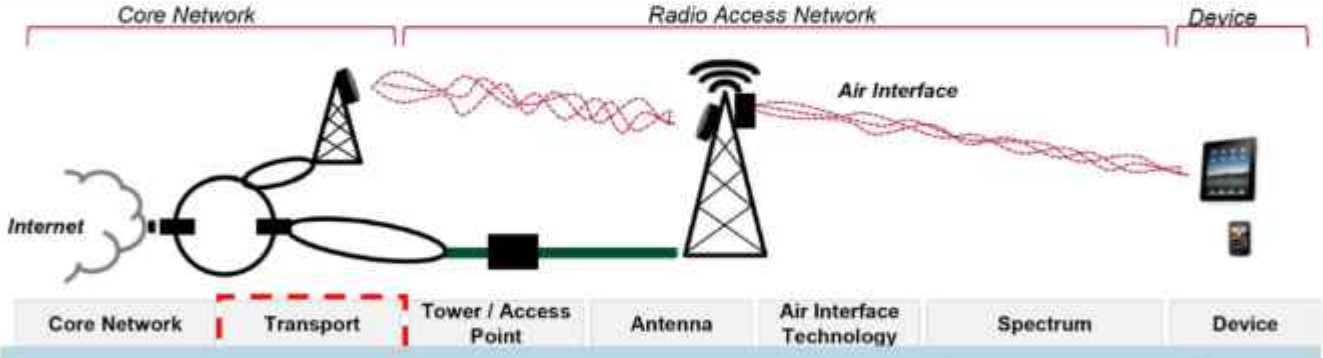


Image 52: How mobile phone calls go from the handset to the cell tower (Radio access nodes), then backhaul through satellite or optical fibre cables, then again to the RAN and then to the handset
(Source: What is Backhaul? Wired vs Wireless, Fiber vs Ethernet - Dgtl Infra)

Given the criticality of this sector to all aspects of the modern economy, citizens' daily lives, and national security, staying dependent on imported products was not an option. In recent years, efforts were made by the DoT, the MeitY, and the OPSA to remedy the situation, and have started bearing fruit.

Leveraging one of the largest telecom markets in the world, and some of the strongest IT companies in the world, the government seeded efforts to create a domestic Radio Access Network system. The government's Center for Development of Telematics (C-DOT), Tata Consultancy Services (TCS) and Tejas Networks Ltd. came together to develop a domestic 4G/5G network including both RAN and Core RAN. This system was expeditiously tested[147] by BSNL with users in Indian locations, and after effective trials, orders were placed for domestic manufacturing.[148] Interestingly, these developments in telecom infrastructure equipment manufacturing closely mirror India's growth in the handset manufacturing sector,[149] which has been one of the success stories in production and export of goods in recent years.

This push to domestic capability development will not only help India gain self-reliance in this critical sector but also develop Indian companies that can compete in the competitive but critical market of telecom equipment around the world.

4.2.2

INDIA'S 5G JOURNEY

5G or the fifth generation of wireless cellular technology delivers high data speed with ultra-low latency in a reliable manner. It has massive network capacity and the potential to provide a more uniform user experience to a larger number of users. Therefore, it will be a key driver for technological, social, and economic development by increasing the communication capacity of the nation.

Having missed the opportunity to take leadership in previous iterations of telecom equipment standards, India has emerged as a frontrunner in this generation - our 5G journey showcases remarkable achievements in digital transformation and ultimately, the national priority of self-reliance. The quick development and deployment of technologies for 5G in a phased manner are helping empower both consumers and businesses.

India's 5G excellence

India's pursuit of 5G excellence began with its pioneering role in ensuring the inclusion of the Low-Mobility Large-Cell (LMLC) rural use case in the global 5G standards by the International Telecommunication Union (ITU), ensuring comprehensive coverage of 5G even in remote areas. Additionally, another global ITU standard 5Gi, a radio interface technology developed by India was adopted globally in 2020, adding to its position as a growing innovation hub and a leader in developing standards that enable accessibility of 5G technology.[150] India's groundbreaking R&D efforts include the development of a 5G testbed, liberalising the spectrum for open experimentation, and the establishment of the 5G Inter-ministerial committee, all aimed at fostering sector-specific 5G use cases. Table 8 below shows various research and capability related outputs of India in the 5G domain.

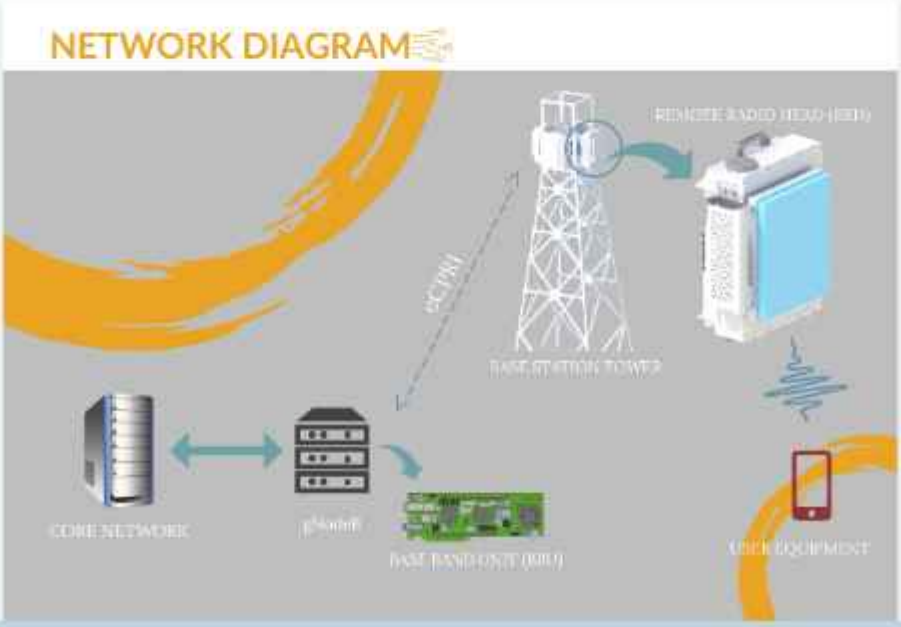


Image 53: Network diagram of the indigenous 5G testbed *(Source: IIT Kanpur website)*

Table 8: Key outputs in 5G R&D in India

Outputs	Description
Indigenous 5G Test Bed	Establishment of a comprehensive test bed in India for research and testing of 5G networks and applications.
Conducting 5G Trials	Collaborative trials in rural, semi-urban, and urban areas to explore the potential of 5G technology.
Expression of Interest for Vertical Engagement and Partnership Program (VEPP)	Initiative facilitating collaboration between user verticals and 5G stakeholders for innovative use cases and partnerships.
Guidelines for Captive Non-Public Networks (CNPN) Licences	Framework for secure, low-latency, and high-throughput communication in developing industries.
Spectrum Auction	Auction of spectrum for IMT/5G services, enabling acquisition by telecom service providers.
Launch of 5G Services	Unveiling of 5G services in India, showcasing use cases in education, health, worker safety, smart agriculture, etc.
Indigenous 5G NSA Core Development	Development and launch of an indigenous 5G NSA Core by C-DoT, strengthening India's 5G infrastructure.
Patents Filed	Over 75 patents filed in 5G and beyond technologies, including Standard Essential Patents (SEPs).
Publications	Research publications, papers, and articles contributing to the advancement of 5G technology.
Training and Capacity Building	Training programs for engineers, scholars, and students to enhance expertise and skills in 5G technology.

India's 5G journey has witnessed the development of robust capabilities such as the 5G indigenous testbed, which, aligned with global standards, has provided a platform for research teams to explore novel concepts and ideas. IIT Kanpur developed the oneM2M, which are globally accepted standards which ensure interoperability and compatibility, facilitating a seamless integration into the global ecosystem. For developing further industrial and research capacity, guidelines for CNPN have been established.

The spectrum auction and the subsequent launch of 5G services by the Hon'ble PM demonstrated the role of India's vibrant private manufacturing and services sector to deliver cutting-edge technologies to the consumer. This milestone unlocks huge possibilities for India concerning high-tech technology and paves the way to bring transformation in crucial areas including agriculture, health, education, transport, logistics, smart cities, and financial inclusion, etc.

The achievements of India's 5G journey will have a profound impact on its citizens.

Improved access to mobile technology and internet connectivity, through a reduction in the cost of devices, data, and broadband services, have made communication more affordable for citizens. With enhanced mobile services and advanced internet-based applications, citizens enjoy seamless video streaming, social media engagement, and access to a plethora of mobile applications. The deployment of 5G networks in India will benefit critical infrastructure security, enable predictive maintenance, facilitate low-delay vehicle-to-vehicle communication, and boost low-cost digital connectivity.

Image 54: National Telecommunications Institute for Policy Research, Innovation and Training, Ghaziabad - the training arm of the Department of Telecommunications
(Source: NTIPRIT website)

India's 5G initiatives align with the national priority of the vision for digital communication, early and efficient deployment of 5G networks, building industrial and R&D capacity, expanding the manufacturing base, and promoting self-reliance through the Aatmanirbhar Bharat initiative.

More importantly, digital connectivity is driven by expanding broadband users and internet access in rural areas, fostering digital access to enable inclusion within the ever-growing market economy, along with providing better access to government services for those who need it most. The downstream impact of the development of this technology will have a wide array of use cases such as the digital transformation of the health, finance, agriculture, and education sector, and many more that have not even been imagined yet.

4.2.3

NATIONAL BROADBAND MISSION

FACTSHEET

Year of Union Cabinet Approval	2019
Nodal Agency	Ministry of Communications
Financial Outlay	INR 7,00,000 crores over a four year period[151]
Key Achievements	• 1,77,550 Gram Panchayats made service ready under BharatNet till June 2022. • 10 Lakh Route KMs of Optical Fiber Cable mapped on PM Gati Shakti National Master Plan (NMP) Portal.
Key Outputs	• 7.23 Lakh towers installed by June 2022 • 35.11% of Telecom Towers/Base Transceiver Stations fiberized

The National Broadband Mission (NBM) bridges the digital divide and aims to provide equitable access to broadband services across India. With the vision of achieving "Broadband for All," the mission focuses on comprehensive measures to ensure universal connectivity and create a robust digital infrastructure. To achieve its goals, the NBM outlines several key objectives. Firstly, it strives for universal and equitable access to broadband services, particularly in rural and remote areas. By leveraging technologies such as optical fibre, radio networks, and satellite, the mission aims to provide last-mile connectivity to all villages, alongside policy and regulatory changes to accelerate digital infrastructure expansion.

The NBM emphasises the importance of collaboration and investments from various stakeholders.[152] It aims to work closely with ministries, departments, agencies, and the Ministry of Finance to secure the mission's implementation resources. The mission also encourages the adoption of innovative technologies, promoting domestic industry participation and advancements in the broadband sector.

Moreover, it focuses on developing effective implementation models for Right of Way (RoW) approvals and encourages states and union territories to establish consistent policies.[153]

NBM focuses on providing broadband access to all villages, enhancing broadband speeds, expanding the optical fibre network for increased fiberization, improving tower density, facilitating the rollout of 5G networks, and developing a Broadband Readiness Index (BRI) to measure infrastructure availability. The successful implementation of the NBM will propel India into the next phase of the digital revolution, fostering inclusive participation, empowering citizens, promoting economic development, and creating a truly connected and digitally empowered society.

The mission aims to ensure affordable and universal access to broadband, bridging the digital divide and fostering digital inclusion across the country.

Governance

The mission will be governed by a Governing Council for Broadband, to be headed by the Minister of Communications and consisting of the members as given below. Its functions will be to provide overall guidance, policy direction, and review the progress of mission activities. It has the authority to decide on the formation of sub-missions in high-priority areas as required and convenes biannually to ensure effective coordination and facilitate the comprehensive development of the mission.

Table 9: Outcomes and achievements

Outputs	Description
Broadband Connectivity to Villages	1,77,550 Gram Panchayats made service ready under BharatNet till June 2022. Scope extended to all villages.
Availability of Broadband Speeds (Mbps)	Average download & upload speeds for mobile broadband across India available on TRAI MySpeed App. Target: 50 Mbps by 2024-25.
Fiberization (Lakh Kms) Cumulative	Optical Fiber Cable (OFC) laid: 34.62 Lakh Km as of June 2022. Target: 50 Lakh Km by 2024-25.
Towers (in Lakhs) Cumulative	Towers installed: 7.23 Lakh as of June 2022. Target: 15 Lakh by 2024-25.
Fiberization of Telecom Towers (%) Cumulative	Telecom Towers/BTSs fiberized: 35.11% as of June 2022. Target: 70% by 2024-25.
Mapping of Fiber	10 Lakh Route KMs of OFC mapped on PM Gati Shakti NMP Portal.
Wi-Fi Hotspots	Out of 1,04,293 installed, 53,600 Wi-Fi hotspots are currently active. BharatNet Phase-I funded by Universal Service Obligation Fund.

Source: Press Information Bureau (2022), Progress of National Broadband Mission (2022)

Conclusion

The NMB plays a crucial role in bridging the digital divide and supporting the national priorities of Digital India. By providing citizens with access to digital services, the mission empowers them to actively participate in e-governance, engage in online transactions, and access valuable information and resources. This initiative fosters inclusive economic development, enhances livelihoods, and promotes digital literacy and awareness among citizens. With a focus on coordination between central and state governments, industry stakeholders, and civil society organisations, the mission aims to ensure equitable and universal access to broadband services, contributing to the sustainable growth of the country and providing citizens with enhanced opportunities for a better quality of life.

4.3

PM GATI SHAKTI NATIONAL MASTER PLAN

FACTSHEET

Year of Union Cabinet Approval	2021
Nodal Agencies	• Ministry of Railways • Ministry of Road, Transport & Highways • Ministry of Ports, Shipping and Waterways • Ministry of Civil Aviation • Ministry of Petroleum & Natural Gas • Ministry of Power • Department of Telecommunications • Ministry of Coal • Ministry of Mines • Department of Chemicals & Petro-Chemicals • Department of Fertilizers • Ministry of Steel • Department of Expenditure • Department for Food and PDS • Ministry of Agriculture and Farmer Welfare • Ministry of Fisheries, Animal Husbandry & Dairying • Ministry of Tourism • Ministry of Commerce and Industry • NITI Aayog • Ministry of Housing and Urban Affairs • Ministry of Electronics and Information Technology
Financial Outlay	INR 1,00,00,000 crores[154]
Key Outputs	• Individual portal created for 22 central ministries and all States/UTs. • Monitoring of 1,380 projects on PMG. • Monitoring of 345 private sector projects. • Resolution of 1,300 project-related issues. • 13 State logistics policies formulated

INTRODUCTION

Imagine a scenario where efficient and interconnected transportation systems connect cities, towns, and villages make commuting seamless and faster; where improved road networks, advanced railway systems, and upgraded efficient airports enable people to access better job opportunities and prosperity; where businesses thrive as costs reduce & supply chains improve through efficient logistics; and where the availability of reliable and fast internet connectivity in even remote areas empowers individuals to access quality education, healthcare, and digital services. The PM Gati Shakti National Master Plan aims to create this transformative scenario, to empower and propel India into a new era of progress and development.

Launched in October 2021, the PM Gati Shakti National Master Plan is set to transform India's infrastructure landscape. With a mission to provide comprehensive and efficient connectivity across modes of transport, it aims to enhance coordination and leverage technology for seamless integration. PM Gati Shakti is built on six pillars: comprehensiveness, prioritisation, optimisation, synchronisation, analytical insights, and dynamism.[155] It integrates existing initiatives, promotes cross-sectoral interactions, identifies critical gaps, synchronises activities, provides comprehensive data through spatial planning tools, and enables real-time monitoring of projects. This holistic approach enhances coordination, decision-making, and progress tracking, ensuring effective implementation of the master plan.

Governance

The institutional framework for implementing the PM Gati Shakti plan consists of three tiers: the Empowered Group of Secretaries (EGoS), the Network Planning Group (NPG), and the Technical Support Unit (TSU). The EGoS, headed by the Cabinet Secretary, comprises Secretaries of 18 central ministries and the Head of the Logistics Division as Member Convenor. Its primary role is to review and monitor the implementation of PM Gati Shakti, ensuring logistics efficiency. The EGoS is empowered to prescribe a framework and norms for any future amendments to the Master Plan.

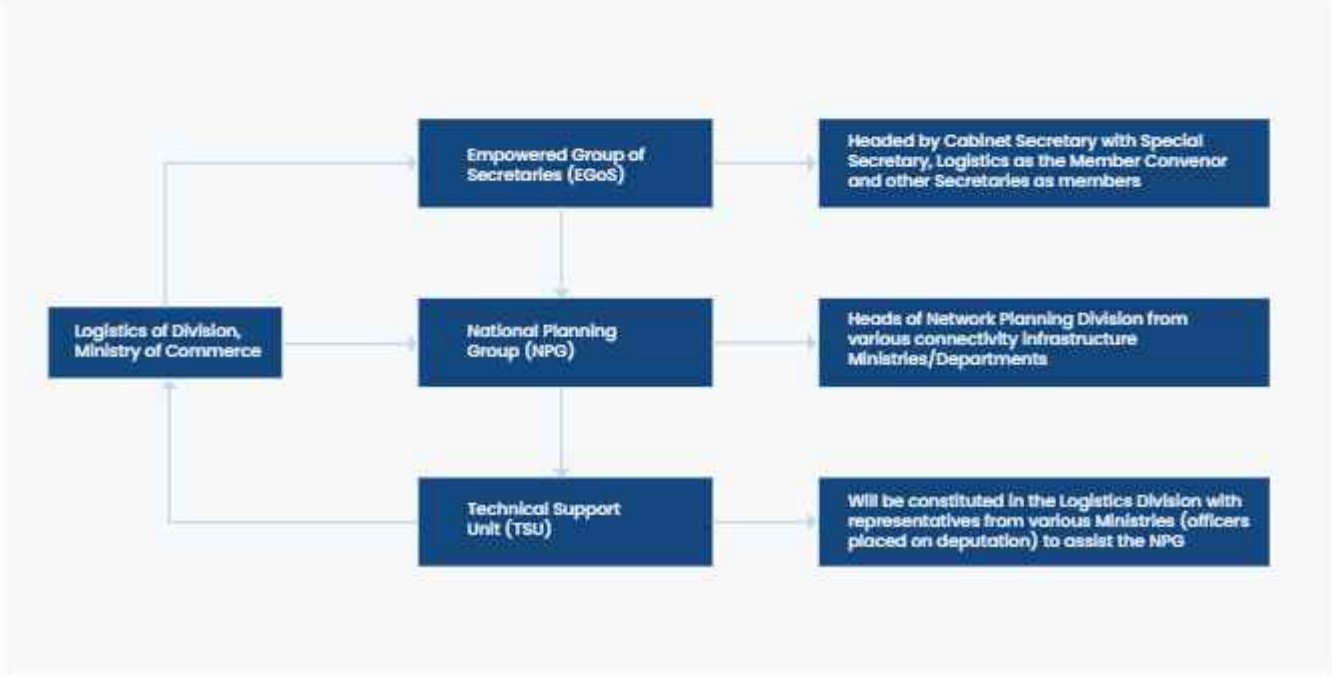


Figure 10: Governance framework. *(Source: Gati Shakti FAQs)*

Table 10: Achievements and outputs

Output	Description
Data layers on PM Gati Shakti NMP	• Individual portal created for 22 central ministries and all States/UTs. • More than 1,900 data layers uploaded from concerned ministries/departments and states.
Capacity Building	• Live demonstration of NMP conducted for 21 central ministries. • 51 workshops completed, attended by over 2,500 participants from central ministries. • 1st module of iGOT training on PM Gati Shakti uploaded • 102 universities identified in 32 States/UTs to offer courses on PM Gati Shakti.
Institutional framework	• EGoS at the national level is operational with 3 meetings held. • EGoS was formed by all 36 States/UTs. • NPG at the national level is operational with 33 meetings held. • NPG was formed by 35 States/UTs.
Formulation of State Logistics Policies	• 13 State logistics policies have been notified and uploaded on DPIIT website for Andhra Pradesh, Assam, Chhattisgarh, Gujarat, Haryana, Himachal Pradesh, Kerala, Madhya Pradesh, Maharashtra, Manipur, Mizoram, Telangana, and Uttar Pradesh.
Impact of Project monitoring mechanism	• Monitoring of 1,380 projects on PMG. • Monitoring of 345 private sector projects. • Resolution of 1,300 project-related issues. • NPGs have held 40 meetings on 61 project proposals.
PM Gati Shakti-related Project by states	• Submission of action plans by states. • Conduct eight screening committee meetings for 17 states. • Recommendation of the state action plan to DOE for 5 states.
Development of applications/tools on NMP	• Development of 12 customized decision-making tools on PM Gati Shakti NMP, including project planning, land parcel evaluation, cost estimation, and forest intersections, among others.

Source: One year of PM Gati Shakti – National Master Plan (Ministry of Finance, 2022)

Conclusion

The PM Gati Shakti National Master Plan is a transformative initiative that directly benefits citizens by enhancing connectivity, reducing travel time, and optimising logistics for the seamless movement of people, goods, and services. The resulting employment opportunities and economic stimulation greatly improve livelihoods and overall quality of life. Aligned with national priorities, including the ambitious goal of a $5 trillion economy, the plan's focus on seamless multimodal connectivity, efficient logistics, and world-class infrastructure paves the way for sustainable development and accelerated economic growth. By addressing key sectors such as agriculture, renewable energy, power transmission, shipping, aviation, road transport, and railways, the master plan ensures comprehensive development throughout the nation. Thus, creating a scenario similar to what we imagined above - where through this initiative, a prosperous future is shaped for all.

4.4

WASTE TO WEALTH

Waste generation in urban areas of India will be 0.7 kg per person per day in 2025, approximately four to six times higher than in 1999.[156] Back in 2016, 62 million tonnes of waste used to be generated annually in the country, out of which 5.6 million tonnes was plastic waste, 0.17 million tonnes was biomedical waste, hazardous waste generation was 7.90 million tonnes per annum, and 15 lakh tonnes was e-waste.[157] Though rapid urbanisation and population growth present an enormous challenge for the country, with the right policy framework and action, this challenge can be turned into a golden opportunity.[158]

To tap this opportunity, the Office of the PSA has established a PMU in partnership with Invest India, India's National Investment Promotion & Facilitation Agency.[159] The Waste to Wealth mission aims to identify, test, validate, and deploy technologies to treat waste to generate energy, recycle materials, and extract resources of value and provide a technology database of national and international technologies to support Urban Local Bodies address their waste challenges.[160]

Key initiatives

To date, the Waste to Wealth Mission has supported 140+ technologies dealing with waste disposal and utilisation.[161] Challenges such as Cleaning and Restoring India's Water Bodies Challenge and Biomedical Waste Treatment Innovation Challenge were hosted to encourage startups, industry and researchers to focus on the problem of waste generation.[162] In addition, the office of the PSA introduced the Swachhta Saarthi Fellowship (SSF) in 2021[163] intending to recognize students, community members and sanitary workers/self-help groups, and municipal/ sanitary workers who are engaged in tackling the challenges of waste management, scientifically and sustainably. The latest cohort of fellowships was launched in 2023. Under the SSF, the fellows work on innovative mechanisms to generate wealth from waste and are supported with nominal monthly fellowships for a period of one year. Some of the technologies developed and successfully tested under the Waste to Wealth mission include:

- **Cleaning of Barapullah Drain**
  - Collaboration between the OPSA and South Delhi Municipal Corporation (SDMC)
  - The drain cleaning excavator named "Drain Master DM-80" developed by M/s Cleantec Infra Pvt. Ltd., Mumbai as an indigenous amphibious barge mounted backhoe with skip used for the cleaning of Barapullah drain
  - For desilting and removing municipal solid and construction & demolition waste from identified stretches of the Barapullah drain.

- **Semi-Automatic Waste Segregation at Kasturba Dhalao[164]**
  - Every day 2,200 tons of fresh waste generated by people in East Delhi finds its way to Ghazipur Landfill which has already exhausted the space for dumping around 10 years ago
  - XAPER, a decentralised auto segregation, and composting system developed by E3 Waste Solutions was deployed for the segregation of solid waste
  - Using this technology, 560 metric tons waste from Ghazipur was diverted in the Year 2020-21.

Radiation Technology for Sludge Hygienisation

Sewage sludge is a rich source of organic carbon and micro and macronutrients, but it contains pathogenic microbes. However, pathogen-free sludge availability in farmlands provides a healthy and economic way to increase production yield, improve soil health, and make full use of the potential of sewage sludge. Radiation technology can be used to convert municipality waste into useful organic fertilizer. BARC has established pilot plants in Ahmedabad and Indore for demonstration of this technology. This technology has potential for use in bigger cities, to address the waste disposal issue on a large scale. To achieve this:

- An Advanced Effluent Water Treatment Plant based on ozonation technology was commissioned (2023) with 750 Litre Per Hour (LPH) capacity at ONGC Mehsana for field demonstration to treat oil-contaminated effluent water and make it suitable for agricultural use in a rain-parched adjoining area.
- Three hybrid-granular Sequencing Batch Reactor (hgSBR)[165] technology-based Sewage Treatment Plants with capacities ranging from 50 to 150 Kilo Liters per day (kLD) have been operationalised at Surat, Shirdi and Tiruchirapalli for treating municipal wastewater. Approximately ten more private companies have entered into an agreement during 2023 for commercialisation of the *patented technology*.

5

AGRICULTURE, LIVESTOCK AND BIOTECHNOLOGY

There is perhaps no other sector where India reaching Aatmanirbharta has been so successfully demonstrated, as in the field of agriculture. For a nation where two third of the population is dependent on agriculture and livestock rearing,[166] this is a crucial progress.

Much of this progress has been driven by advancements in the field of biotechnology. The Green Revolution was a product of research and development and resulted in India becoming a food-surplus nation.[167]

Recognising the importance of S&T in this sector, India has consistently invested in research and development for agriculture, livestock and biotechnological advances over several decades through several different missions, programs, and initiatives.

This section looks at some of these efforts including the National Digital Livestock Mission (NDLM) and the AROMA Mission.

5.1

ADVANCEMENTS IN AGRICULTURE, LIVESTOCK AND BIOTECHNOLOGY

Image 55: Agriculture is central to the Indian economy *(Source: CSIR inputs)*

Agriculture sustains the livelihood of about half of India's population. With India surpassing China as the largest population in the world recently,[168] and the need for sustenance of livestock and cattle, the Indian agriculture sector is galvanised to meet enormous demands of food, fodder, fibres, fuels, etc. The share of the agriculture and allied sector in the total Gross Value Added (GVA) of the economy is almost 18.8% in 2021-22.[169] Shrinking land holdings, soil degradation, nutrient deficiencies, natural calamities, inadequate infrastructure for processing and storage, or post harvest losses and ensuing climate changes are some of the problems faced by the sector. These lead to issues of sustainable productivity, quality of produce, biotic and abiotic stresses, thus impacting sustainable agricultural production.

Such challenging issues are being constantly tackled or mitigated through advancements in crop production technologies supported by modern molecular biology and biotechnology, particularly genomics, proteomics, transgenics and gene editing technologies. The modern technologies like speed breeding opened new vistas for the development of new plant varieties that are climate resilient, bio-fortified and suitable for the varying growing conditions of our nation. Technology based modern agriculture practices such as GIS, remote sensing, GPS, etc. are continuously providing solutions for improvement in production, productivity and profitability of the farmers. As per the Geospatial Artha Report, 2022, the India geospatial market for the agriculture sector is estimated to be INR 52.39 crores in 2022 and is forecasted to grow up to INR 67.65 crores in 2025.[170] Further, the GIS and Spatial Analytics market is forecasted to increase from INR 16.33 crores in 2022 to INR 21.13 crores in 2025.

Overall, the decadal growth in production of food grains, oilseeds and commercial crops in 2022-23 (3rd Advance Estimates) as compared to 2013-14 is given in Table 11 below:

Table 11: Crop Growth in India

Crop *(in lakh tonnes)*	**2013-14**	**2022-23***	**Growth (%)**
Rice	1,066.46	1,355.42	27.09
Wheat	958.50	1,127.43	17.62
Maize	242.60	359.13	48.03
Total Pulses	192.57	275.04	42.82
Total Foodgrains	2,650.47	3,305.34	24.70
Groundnut	97.14	102.82	5.84
Soyabean	118.61	149.76	26.26
Rapeseed & Mustard	78.77	124.94	58.61
Total Oilseeds	327.49	409.96	25.18
Sugarcane	3,521.42	4,942.28	40.34

Source: Inputs from Ministry of Agriculture and Farmers Welfare

Radiation technologies to improve seed and crop productivity

- BARC uses radiation-based mutation breeding to create genetic variability as one of its core programs in enhancing crop productivity. Out of the globally documented inventory of over 3,300 enhanced mutant varieties, approximately 340 have originated from our nation. These varieties have contributed significantly to the enhancement of farmers' income.

- A Genetically improved bio-fungicide *Trichoderma virens* strain has been developed by gamma-ray induced mutagenesis by BARC. This mutant produces up to 3-fold more anti-fungal compounds and shows better protection against fungal infections of plants.

- Over the years, DAE and BARC have made significant strides in the application of radiation technology to diverse species. This has led to the creation of high-yielding varieties with a range of characteristics, including tolerance to abiotic/biotic stress, larger seed size, and enhanced nutritional properties. Few noteworthy examples in recent years (2018- 2023) are as follows:
  - **Onions:** BARC has conducted R&D and commercial trials that resulted in the development of an integrated operating procedure through which radiation-processed onions can be effectively stored for 7.5 months under specified cold storage conditions. This ensures the availability of quality onions and price stabilisation during the lean period and also reduces post-harvest losses.
  - **Potatoes:** A commercial trial for shelf-life extension of potatoes was performed by BARC with three varieties using gamma irradiation, followed by cold storage. Non-irradiated potato samples completely sprouted within 100 days whereas irradiated potatoes retained the quality attributes without any sprouting till 8 months. Potatoes were found to be suitable for table consumption as well as industrial processing.
  - **Mangoes:** Radiation technology has been extensively used for exporting mangoes to overcome quarantine barriers since 2007. In 2023, India exported more than 2,500 MT which is a significant quantity in comparison with 1,048 MT of average annual exports in the last 5 years. Four food irradiation facilities were involved in this process as per the SOP developed by BARC. Radiation-processed mangoes were exported to majorly four major countries – the USA, Australia, South Africa and Malaysia.

- BARC-hydrogel is a potential soil conditioner that can absorb rainwater or irrigation water several hundred times its mass. It can be applied wet or dry near the plant saplings at any time during the plant growth to provide plants with an early and healthy start. BARC-hydrogel has successfully been tested for afforestation on barren lands of Hingoli, Maharashtra, with the help of the Directorate of Construction, Services & Estate Management (DCSEM), DAE. It enabled survival of plants (neem and tamarind) by reducing water requirement up to 50%, and vegetative growth was comparable to control.

Key interventions and achievements

To make Indian agriculture aatmanirbhar and future-ready, several initiatives like the National Mission for Edible Oils (NMEO), Pradhan Mantri Fasal Bima Yojana (PMFBY), Soil Health Cards, National Mission on Natural Farming (NMNF), Rashtriya Krishi Vikas Yojana (RKVY), National Mission for Sustainable Agriculture (NMSA), the promotion of scientific warehousing and the adoption of drone technologies, creation of Agri-Infrastructure Fund, Promotion of FPOs, National Beekeeping and Honey Mission (NBHM), Per Drop More Crop (PDMC), Rainfed Area Development (RAD), E-NAM, Kisan Rail, Mission for Integrated Development of Horticulture (MIDH), creation of startup ecosystem in Agriculture through Knowledge Partners (KPs) and Agribusiness Incubators (R-ABIs), Sub- Mission on Seeds and Planting Materials (SMSP), Promotion of Mechanization through Custom Hiring Centres (CHCs), Agri-Drones and AgriStack have been undertaken.[171]

The following information further illustrates the size and scale of agriculture and its impact on the Indian economy.[172]

- Between April 2000 and March 2022, a FDI equity inflow of around $2.55 billion was attracted by the Indian food processing sector.
- India's agriculture exports touched a historic high of $50 billion (FY 2021-22) and the highest-ever exports were achieved for staples like rice, wheat, sugar, other cereals and meat.[173] As per the provisional figures released by the Directorate General of Commercial Intelligence and Statistics (DGCI&S), agricultural exports have grown by 19.92% during 2021-22 to touch $50.21 billion. The exports further increased by 5.79% during 2022-23 to $53.15 billion.
- The R-ABIs supported 1,176 agri startups associated with precision agriculture, drones, farm mechanisation, post harvest, food technology & value addition, agri-logistics & supply chain, waste to wealth, organic farming, animal husbandry, dairy & fisheries, secondary agriculture etc. with financial assistance of INR 75.25 crores. To provide an impetus to the efforts, an Accelerator Fund of INR 500 crores has been created.
- India received about INR 8,204 crores in agri-tech funding between 2017 and 2020 and ranks third in agri-tech finance and number of agri-tech startups.
- To ensure speedy and easy access to the newer technologies, ranging from crop varieties, seeds, planting materials, agro-techniques, livestock rearing, fisheries, the nationwide network of 729 Krishi Vigyan Kendras is strengthened with enhanced digital access and advisory capabilities.
- Since 2014, 2,279 high yielding varieties of field crops were released, out of which 1,888 (83%) are climate resilient and 113 are bio-fortified (for 16 crops). The promotion of climate resilient varieties led to enhanced production even during two consecutive stress effected years viz. 2021-22 (315.61 million tones) and 2022-23 (330.53 million tones). The productivity of all major crops also increased significantly (Rice: 13.47%; Wheat: 25.96%; Jowar: 27.60%; Bajra: 14.42%; Pigeonpea: 22.36%; Chickpea: 36.90%; Lentil: 41.99%; Rapeseed/Mustard: 39.52%; Sunflower: 38.99%; Sugarcane: 15.49%; Potato: 9.09%).
- The Minimum Support Price (MSP) for all mandated crops was fixed at least one and half times the cost of production. Thus, there was a significant enhancement in MSP like for paddy it increased from INR 131 per tonne to INR 204 per tonne, for wheat from INR 140 per tonne to INR 212.5 per tonne etc. The procurement under Kharif and Rabi during 2021-22 enhanced to 3,182,591.64 MT of pulses, oilseeds and copra having value of INR 17,478.31 crores benefitting 1,468,699 farmers. During the current year 2022-23, the quantity increased to 3,657,241.01 MT of pulses, oilseeds and copra valued at INR 20,742.34 crores benefitting 1,633,631 farmers.
- In poultry sector, with improved backyard chicken varieties, population of birds increased by 45.8% that is from 217.49 million in 2012 to 317.07 million in 2019. This was achieved with distribution of 136.04 lakh improved chicken germplasm.

- Diagnostics and Vaccine for African Swine Fever Virus in Pigs was developed by CRISPR/Cas9 Gene Editing technology.
- Under the worlds' largest DBT based Scheme PM-KISAN, more than INR 2.42 lakh crores has been transferred to more than 11 crores farmers since 2019.

- **PMFBY launched in 2016 enrolled more than 48.26 crores farmer applicants and about 13.63 crores applicants received claims of over INR 136,923 crores. The share of premium paid by the farmers had been INR 29,185 crores, indicating that for every INR 100 paid as premium they received INR 469 as claim. For further improving the transparency in transactions, DigiClaim module through National Crop Insurance Portal (NCIP) has been launched.**

- Institutional credit for agricultural sector increased from INR 7.3 lakh crores in 2013-14 to approximately INR 18.5 lakh crores in 2022-23. The benefit of concessional institutional credit through Kisan Credit Card (KCC) at 4% interest per annum has been extended to Animal Husbandry and Fisheries farmers also. Since February 2020, a special drive has been undertaken to provide KCC to all beneficiary farmers of PM-KISAN.
- Under Parampragat Krishi Vikas Yojana, since its launch in 2015-16, till date INR 1,854.01 crores has been released, 32,384 clusters (20 ha each) formed, 6.53 lakh ha area covered and 16.19 lakh farmers benefitted. In addition, under Namami Gange Programme, INR 198.22 crores has been released for 6,181 clusters covering 1.23 lakh ha area. The Jaivikkheti Portal has 6.09 lakh registered farmers on date.
- The Mission Organic Value Chain Development for North Eastern Region, with INR 919.42 crores since 2015-16 created 379 Farmers' Producer Organisations/-Farmers' Producer Companies (FPO/F-PC) covering 1,89,039 farmers, 172,966 ha area, 367 Collection/ Aggregation/Grading/Custom Hiring Centres, 94 processing/pack houses etc. Seven NE States developed their own brands for marketing.
- Since the inception of Agri Infrastructure Fund (AIF) in 2020, an investments of INR 40,065 crores have been mobilised in agriculture sector including 9,655 warehouses, 6,128 primary processing units, 5,281 custom hiring centres, 1,639 sorting and grading units, 1,033 cold storage projects, 164 assaying units and about 5,775 other post harvest management projects and community farming assets.
- India is producing 133,200 MT of Honey (2021-22) with an export of 74,413.05 MT during the same year. The 'Madhukranti Portal', with traceability features for source of honey and other bee products, has 13,958 Beekeepers/Societies /Firms/-Companies associated with Honey and has 21.22 lakhs honeybee colonies registered with National Bee Board (NBB).
- An area of 78 lakh ha has been covered under Micro-irrigation through PDMC Scheme since 2015-16. Under Micro Irrigation Fund (MIF) with National Bank for Agriculture and Rural Development (NABARD), projects worth INR 4,710.96 crores covering 17.09 lakh ha have been approved.
- Agricultural mechanisation, considered to be most vital intervention for reduction in costs of cultivation as well as drudgery in farm operations, received enhanced focus since 2014-15 with INR 6,405.55 crores, providing 1,523,650 machines and equipments to farmers, along with 23,018 custom hiring centres, 475 high-tech hubs, 20,461 farm machinery banks etc. For addressing the problem of residue burning in certain states, INR 3,138.56 crores were released since 2018-19 for crop residue management interventions, including 39,932 CHCs, 2.42 lakh machines etc.
- Standard Operating Procedures for Kisan Drones for various crops were developed and under Sub-Mission on Agricultural Mechanization (SMAM) INR 134.56 crores have been released for their promotion. 317 drones were provided for demonstrations in 79,070 ha area along with 347 drones to farmers and 1,573 drones to CHC.

- **The e-NAM Portal is integrated with 1,361 Mandis of 23 States and 04 UTs, and more than 1.75 crores farmers and 2.45 lakh traders are registered on the portal. First Kisan Rail was launched in July 2020 and so far 2,359 services on 167 routes have been operated.**

- The Mission for Integrated Development of Horticulture (MIDH) initiated since 2014-15 brought an additional area of 12.61 lakh ha under identified horticultural crops. Moreover, 856 nurseries have been established, 1.38 lakh ha of old orchards were rejuvenated, 51,465 ha covered under organic farming, 2.56 lakh horticultural equipments distributed, 1.11 lakh post-harvest units established, 13,930 market infrastructures set-up and more than 9.0 lakh farmers trained for various horticultural activities making this sector enabled to contribute about 33% to the Agriculture GVA (AgriGVA).
- To cater to the global needs establishment of ICAR- Indian Institute of Millets Research as Centre of Excellence for Global R&D Hub for Millets (Shree Anna) in India with INR 250 crores is underway and a new initiative "Enhancing climate resilience and ensuring food security with genome editing tool" wit INR 500 crores is planned.
- The promotion of Millets under International Year of Millets-2023, resulted in increase of eligible PLI Scheme beneficiaries and production of millet increased from INR 42.0 crores in 2019-20 to INR 196.4 crores in 2022-23, which is set to increase to INR 19,000 crores by 2026-27. Further, to provide easy access to such products a special Millet Corner has been created on the GeM portal. In Kharif marketing season of 2022-23, 5.78 lakh tones of millets were procured for distribution under TPDS, ICDS, PM-POSHAN/Mid Day Meal Scheme etc.
- Under Sub-Mission on SMSP initiated during 2014-15, so far 6.33 lakh Seed Villages have been established, 57.43 lakh quintal seeds distributed, 1,511.90 lakh quintal of quality seeds produced and 2.59 crores farmers benefited. A seed village is described by the ICAR to mean a village wherein trained group of farmers are involved in production of seeds of various crops and cater to the needs of themselves, fellow farmers of the village and farmers of neighboring villages in appropriate time and at affordable cost. Also a National Seed Reserve of 26.40 lakh quintals of different varieties of seeds have been maintained for natural calamities. With an aim of effective monitoring of seeds, Seed Authentication, Traceability and Holistic Inventory Portal (SATHI Portal) has been developed.
- To create a coherent Digital Agriculture Ecosystem, involving domains of agriculture, information technology, program planning etc 'Agristack' with foundational layers of core registries, base databases, farmers' database, geo-referenced plots, crop survey, crop planning, soil mapping, data exchange and others is under development.

Image 56: High Yield Variety of Geranium (CIM-Bharat) growing in field *(Source: CSIR inputs)*

Agricultural advancements in biotechnology

The Agriculture Biotechnology programme of the DBT promotes sustainable agriculture through innovative research in the country. DBT supports various aspects of agricultural research in the area of basic research, gene-editing, pre-breeding, transgenics, heterosis breeding and molecular breeding. Abiotic and biotic stress tolerance in crops is the main target area of research.

Till a few years back, the focus of agricultural R&D in India was tilted towards productivity of the crop varieties and in the process specific, nutritional traits were not in the priority in most of the food security crops. An effective national-level dedicated effort in the development of bio-fortified varieties of these crops was lacking, which has been remedied recently with release of 113 biofortified varieties of 16 crops. Enhancing genetic gains is critical for ensuring food security to the ever-increasing world population and molecular breeding, gene editing, genomic selection, etc have the potential to rapidly break yield stagnation in crops. So far India's crop improvement program has mainly relied on conventional breeding and/or to some extent marker-assisted breeding. Improvement of oilseed is one of the priority areas of the DBT as India has a high level of import dependency on edible oils. Similarly, another area of improvement in agriculture research is the enhancement of pulses and millets (Shree Anna).

Biotechnology R&D and its achievements

Amongst the many ongoing research developments in the field of agriculture, some of the most notable are as follows:

- Development of genomic resources and their application in crop improvement: Genomic resources for crops, three insects, 21 microbial and eight pathogenic species including whole genome sequences were developed. Eight genes, responsible for specific agronomic traits, were identified in six crops by allele mining and gene-based association analysis, of which one gene (rice SHMT3) was validated by genetic transformation. Developed a quick and reliable qPCR and LAMP-based diagnostic assay to detect Karnal Bunt *(Tilletia indica)* in wheat.
- In the Dairy sector, early pregnancy diagnosis in cattle and buffalo using pregnancy associated proteins (PAGs/miRNAs) by Lateral Flow Assay was developed and is being validated.
- CRISPR/cas9 gene editing technology was adopted for development of diagnostics and vaccines for African Swine Fever Virus in pigs.

5.2

NATIONAL DIGITAL LIVESTOCK MISSION

Being an agrarian society, livestock holds a very important role in Indian households. Livestock contributes almost 5% towards the national GDP. Nearly 10 crores households undertake livestock activities, which provide a year-round stream of both income and nutrition. India is the world's largest milk producer, a major exporter of buffalo meat, and has a flourishing poultry market. The market size for livestock in India is about INR 9.5 lakh crores growing with a growth rate of 6% annually.

While there are many reasons to rejoice, the sector also suffers from certain persistent issues, namely, scattered ownership of cattle, low disease surveillance and reporting, and low productivity. A 12-digit tab for cattle has been in force in India for a while but there were issues with the implementation of the rule. Till 2014 out of an estimated 29.54 crores bovines, only 10.28 lakh animals were tagged, a negligible number. In the absence of the unique Tag IDs, the sector was functioning more or less in a non-digital way. For instance, it is difficult for small scale farmers to ask for services or access requisite information. Similarly, due to lack of information through integrated channels, artificial insemination & breed improvement services are available to everyone. In addition, disease reporting mechanisms of livestock need strengthening.

Key reforms

A unique identification number system has been developed in India to develop a database for livestock animals wherein the complete life-cycle of animals can be captured and traceability can be established.

Tagging has been made mandatory for participation in Union Government schemes such as:

- Universal Foot and Mouth Disease (FMD) vaccination under the National Animal Disease Control Programme/Livestock Health & Disease Control Programme and
- Nationwide Artificial Insemination Programme (NAIP)

With these interventions till now out of an estimated 29.54 crores bovine population nearly 26.72 crores (90.5%) have been tagged in the field and this database is available for integrating it for various activities.

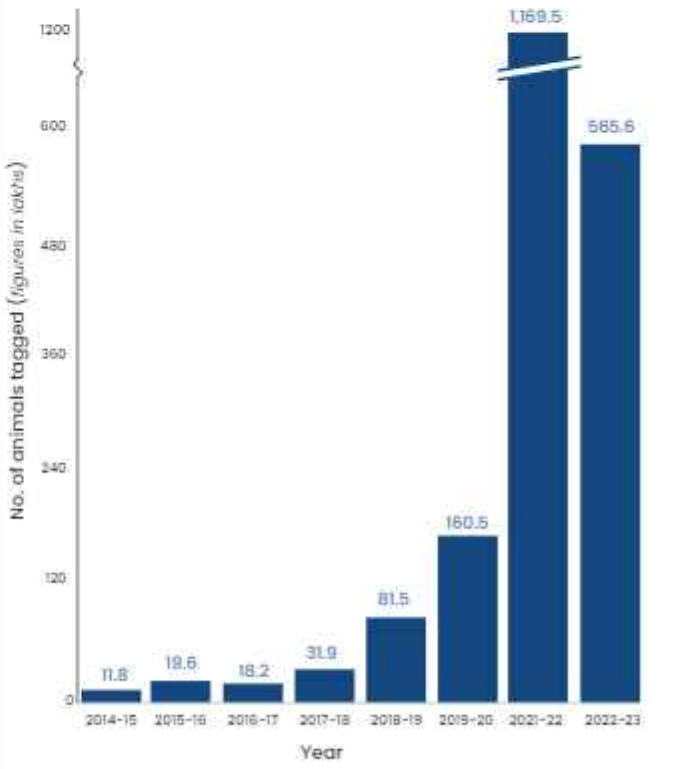


Figure 11: Details of animals tagged in the field from 2014 till 2022 *(Source: Department of Animal Husbandry and Dairying (DAHD) inputs)*

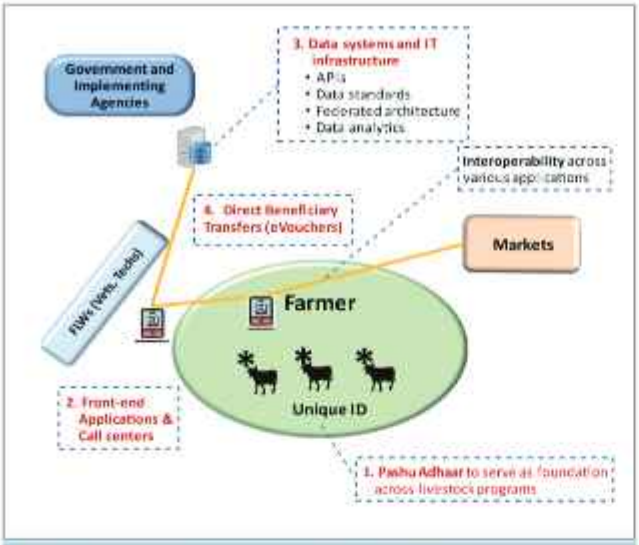


Figure 12: Key components of NDLM
(Source: DAHD website)

The road ahead

A pre-existing digital system called Information Network for Animal Productivity and Health (INAPH) designed for running Progeny Testing/Pedigree Selection (PT/PS) projects was being utilised for running the program so far, which had design deficiencies.

In view of the above, it was decided that a completely new ecosystem would be developed under National Livestock Digital Mission (NDLM). Under NDLM all the static and dynamic information about every tagged animal will be available on an open-source, API-integrated database for all the stakeholders including the farmers. Under NDLM, "Bharat Pashudhan" is envisaged by the Department of Animal Husbandry & Dairying and National Diary Development Board (NDDB) with the guidance from the Office of Principal Scientific Adviser.

The NDLM aims to ensure visibility and uploading of data smoothly by all Frontline Workers (FLWs) and farmers. This will empower the farmers by providing them a medium through Mobile App, Call centre and web interface for fully utilising government facilities, and schemes and availing the services required for the livestock. These services include accessing factsheets of an animal, telemedicine services, and breeding services.

Other than farmers and government workers there is a large group of stakeholders for whom connecting to an integrated database for their functioning is essential such as financing institutions, the insurance sector, and various startups working in this field. All these stakeholders play an important role in the life of a farmer by providing services such as financing, insurance, treatments, traceability, etc. and for their work, they require a credible and integrated database system to enable them to make decisions in the best interest of the sector.

Bharat Pashudhan has been envisioned as a secure, credible, and integrated database system for the needs of such stakeholders. In order to facilitate them the IT system is being designed on open source architecture for an API-based integration environment for seamless information exchange across the sector as a service enabler tool. Under the NDLM, the following achievements have been made so far:

- Existing Unique identification Tag ID database has been successfully migrated to cloud.
- New application "Bharat Pashudhan" for FLWs has been developed and has been made Go-live, details of different phases is detailed as under:
  - In Uttarakhand w.e.f. 10th of April 2023
  - In another six States/UT of Himachal Pradesh, Goa, Jammu & Kashmir, Ladakh, Chandigarh and Puducherry w.e.f. 1st of June 2023.
- Sero-surveillance and Sero-monitoring Module is live since June 2022 and is being utilised by Regional Disease Diagnostics Laboratories (RDDLs) for processing the field samples for disease monitoring purposes.

Table 12: List of indicative future activities to be carried out under NDLM

Activity	Description
Sector App "1962"	Farmer facing app under development
Disease Monitoring and Control	An integrated Disease monitoring and control system and associated Lab centre which will be using latest AI/ML tools for analysis and R&D purposes is being established at National Institute of Veterinary Epidemiology and Disease Informatics (NIVEDI), Bangalore as a part of NDLM project.
Breed Improvement	Using data integration to create a breeding program for achieving the best quality germplasm.
Product Traceability	The traceability will improve product quality for the consumers and also provide opportunities for branding of products and increased income for the farmer.
Livestock census	Livestock census exercise will be undertaken through NDLM app only and this exercise will serve both the purposes of census as well as database cleansing and will keep the database updated in near real time basis.

5.3

AROMA MISSION

FACTSHEET

Year of Union Cabinet Approval	2016-2020 (Phase I) 2021-2023 (Phase II) 2023-2026 (Phase III)
Nodal Agency	Council of Scientific & Industrial Research (CSIR)
Key Objectives	To support and encourage farmers to cultivate, process and market plants with aromatic medicinal properties. Nine high value aromatic crops identified by CSIR- Indian Institute of Integrative Medicine (CSIR-IIIM) for the Aroma Mission include Lemongrass, Rosagrass, Lavender, Rosemary, Jammu Monarda, Salvia Sclaria, Mentha species, Ocimum species and Pelargonium Graveolens.[174]
Key Achievements	In phase I of CSIR Aroma Mission, more than 5500 hectares of additional area was brought under captive cultivation of aromatic cash crops. CSIR provided technical, infrastructural and procurement mechanisms to farmers of these crops.
Next Steps	Launch of CSIR Aroma Mission Phase III (2023-2026)

CSIR Aroma Mission is aimed towards catalysing rural empowerment through cultivation, value addition and marketing of aromatic plants.[175] The phase I of the mission lasted between 2016-2021. Phase II of the Mission was launched in 2021.[176] The following are some significant achievements of CSIR-IIIM during the phase I of the CSIR-Aroma Mission:[177]

- Brought more than 5,500 ha (for all participating labs of CSIR) of the additional area under captive cultivation of aromatic cash crops particularly targeting rain-fed /degraded land across the country.
- Provided technical and infrastructural support for distillation and values-addition to farmers/growers all over the country.
- Enabled effective buy-back mechanisms to assure remunerative prices to the farmers/growers.
- Made progress in value-addition of essential oils and aroma ingredients for their integration in global trade and economy.

Image 57: Some of the products released under the AROMA mission include FMCG goods such as toothpaste and pain relief gel made from AROMA-developed variants (Source: CSIR AROMA website)

Purple revolution under the CSIR Aroma Mission[178]

Lavender is commercially one of the best known essential oil-bearing plants, which is grown for essential oil and dry flowers. Because of its delightful odour, Lavender oil has found wide applications in flavour, perfumery and cosmetic industry. It is also used in therapeutics as antispasmodic, and carminative. Recently, as aromatherapy has become increasingly popular, Lavender oil has found application as a stress buster or brain relaxant.

The global demand for Lavender oil is estimated at around 12,000 tons/ year, whereas domestic consumption of Lavender oil is more than 250 tons/year.

Under CSIR-Aroma Mission, high value essential oil-bearing Lavender crop was introduced to the farmers of temperate regions of Jammu viz., Doda, Kishtwar, and Rajouri districts. Till March 2021 under CSIR-Aroma Mission, Quality planting material (QPM) of Lavender, i.e., more than 8 lakh rooted plants of Lavender were provided free of cost to more than 500 farmers in the Jammu region for >140 acres of land. Besides free QPM of Lavender, free technical knowledge and essential oil distillation facilities were provided to the farmers. Field demonstration for plantation of Lavender was also given to the farmers. Detailed information about agro-technology and field management practices was provided to the farmers. Lavender cultivation in the Jammu division is immensely helping in alleviating the income of the marginal farmers of the region. Lavender has become vastly popular among small and marginal farmers of the temperate regions of the Jammu division. Farmers have produced more than 800 liters of lavender oil worth INR 80 lakhs between the years 2018-2020.

Image 58: Promoting drought-tolerant remunerative aromatic crops in Vidarbha and Bundelkhand *(Source: CSIR AROMA website)*

Key objectives of CSIR Aroma Mission Phase III (2023-2026)

- Development of sustainable Aroma villages/clusters.
- Design and development of efficient distillation units based on energy from renewable resources.
- Development of efficient and low-cost tools and techniques for determining the major aroma chemicals and detection of adulterants in the essential oils for the supply of quality raw materials especially for the international market.
- Valorisation of spent biomass to utilise the waste for value addition thus increasing the farmers income.
- Development of safe essential oil-based products for human and veterinary use to promote startups and innovations.
- Genomic resources data generation for important crops which could be exploited for developing improved genotypes/varieties.
- Development of resource-efficient and climate-resilient varieties of aromatic crops to reduce the input cost for cultivation and sustaining climate adversaries.
- Organising Training/awareness programs for the development of human resources skilled in aroma crops cultivation, processing and value addition.
- Promoting entrepreneurs/startups in the aroma sector for generating planting material, processing units, marketing of essential oils and manufacturing of aroma based value added products.
- Increasing the area under cultivation of selected aromatic crops by another 16,000 hectares in the next three years for meeting the aroma industry demand and helping in increasing the farmer's income.

6

HEALTH

Community health worker gives a vaccination in Odisha state, India
Photo: Pippa Ranger/DFID, licensed under CC BY 2.0.

S&T research form the bedrock of improvements in health. While research and development play an important role in the field of medicine, it plays an equally important role in the field of public health. Public health is the science of protecting and improving the health of people and communities.[179]

India has seen many improvements in public health over the last several decades. Decreased rates of infant mortality,[180] maternal mortality[181] and increased life expectancy[182] have all contributed to safer and longer lives for Indians today.

There have been many areas in medicine and public health where India has shown tremendous advancements and improvements. Consistent efforts and investments from the Ministry of Health and Family Welfare (MoHFW), research funding and conducting bodies such as the Indian Council of Medical Research (ICMR), DBT, DAE among others have played a crucial role in research and implementation of health programs for both infectious diseases and non-communicable diseases (Cancer and others).

However, the single best example today, one that is vivid in our memories given recent events, is the Indian vaccine story.

The next section takes a walk through India's vaccine story. It starts from before the pandemic, to acknowledge the investments and efforts that had been previously done, which allowed the nation to mount a concerted and intense push to develop and manufacture vaccines to safeguard the entire nation and the world when the time came.

Image licensed from freepik.com

6.1

INDIA'S VACCINE STORY

The benefits of vaccines in the 20th and 21st centuries are hard to exaggerate. Referred to as "the single most life-saving medical innovation ever in the history of medicine",[183] vaccines have been credited with saving 50 million lives between 2000 and 2019 and will avoid 52 million deaths in children under the age of 5 years, between 2000 and 2030.[184] Vaccines have led to the eradication of diseases such as smallpox and more recently, the near-eradication of polio.

Even before the onset of the COVID-19 pandemic, 60% of the world's vaccines were produced in India.[185] UNICEF programs and many low-income countries depend on high-quality, affordable vaccines produced in India.

Universal Immunisation Program

In India today, routine immunisation is credited with having saved children's and mothers' lives and has reduced the burden of mortality and morbidity. Our immunization program, better known as the Universal Immunisation Program (UIP) is arguably the largest in the world and serves a birth cohort of nearly 25 million newborns, approximately 100 million children up to the age of 5 years, and 30 million mothers for vaccines and boosters.[186] India eliminated maternal and neonatal tetanus, in April 2015, well before the global deadline of December 2015.[187]

Under the UIP program, vaccinations against 12 vaccine-preventable diseases are provided free of cost at government centers. Mission Indradhanush, a special vaccination drive launched in December 2014 targeted unvaccinated and partially vaccinated children less than 2 years of age to reach more than 90% full immunisation coverage and unvaccinated pregnant women. While the first two phases of Mission Indradhanush resulted in a 6.7% increase in full immunisation coverage in a year, a survey carried out in 190 districts (covered in Intensified Mission Indradhanush which is the 5th Phase of Mission Indradhanush) shows an 18.5% points increase in full immunization coverage as compared to the National Health and Family Welfare-4 (NFHS-4) survey carried out in 2015-16.

The latest round of the Intensified Mission Indradhanush 4.0, is aimed at vaccinating those children who missed crucial vaccines during the pandemic.

UIP is a feat of logistics management. Delivering vaccines through the length and breadth of the nation is done through a network of Primary Healthcare Centers, hospitals, and vaccination drives and delivered by an army of personnel on the ground. Vaccines require specialised transport, in what is known as a cold-chain supply as many vaccines need to be kept consistently at low temperatures for efficacy without which the potency of the vaccine reduces or in some cases fails. There are more than 29,000 Cold Chain Points (CCPs) across the country where the vaccines are stored and further delivered to the lower-level stores/immunization sessions attached to them.[188]

The country also relies on digital tools to support vaccine logistics requirements. The Electronic Vaccine Intelligence Network, or eVIN, is a smart vaccine logistics system, developed by the United Nations Development Program. GoI monitors vaccine stocks and temperatures and is integrated into the cold-chain system of the country. eVIN allows health workers to provide real-time information on vaccine stocks after each immunisation session. This information is stored on a cloud server so officials can immediately see vaccine availability. A recent evaluation of eVIN showed it saved 90 million vaccine doses, reduced stock-outs by 80%, and gave an estimated future return on investment of nearly 300%.[189]

Both public and private sector investments in vaccine manufacture have resulted in the country being Aatmanirbhar to the point of being able to export vaccines to other countries.

India's strength in vaccine manufacture and delivery has been known for some time. However, over the last several years, the country is also emerging as a strong center for the development of vaccines.

Beyond Manufacturing: India as a hub for vaccine development

Vaccine development is a long and complex process, often spanning multiple years and large costs. Being a process of scientific discovery and translational development, it comes with added risks of failure.

Aside from the risk of scientific failure, vaccines, being a medical product that is administered to humans, have stringent regulatory requirements to prove their safety and efficacy. A process of clinical trials to test vaccine candidates after initial development and animal safety studies, in three stages with increasing sample sizes, is the gold standard for testing the vaccine's safety and efficacy. However, these steps drive up costs and time taken for vaccines to reach the public and increase the unit economics of the vaccine. Many vaccines, especially those developed abroad, are well out of the reach of public health systems in low-and middle-income countries.

This is where India has gained a distinct advantage. Lower costs of production with strict regulations, coupled with unique

Image 59: Rotavac and Ceravac vaccines
(Source: Department of Biotechnology inputs)

financial partnerships between stakeholders have resulted in the development of high-quality affordable vaccines.

Perhaps the best example of this is the development of the Rotavirus vaccine, which is now part of the UIP. The Government of India, along with partners agreed with the vaccine manufacturer Bharat Biotech, where in return for funding to de-risk the development of the vaccine, the manufacturer would promise to sell the vaccine at a low cost of $1 and in large volumes.[190] A similar partnership also supported the development

of the quadrivalent HPV vaccine against cervical cancer, developed by the Serum Institute of India with partial funding from DBT, which received market authorisation in 2023.

Vaccines for Pneumococcal infections in 2017,[191] and Japanese Encephalitis in 2014[192] have been developed through partnerships with global entities for technical support. Similarly, process innovation coupled with technology transfer from global entities, has enabled the development of vaccines for Hepatitis B, Meningitis A and Cholera. A vaccine against Shigella, the second (after Rotavirus) most fatal organism to cause enteric infections in infants, is under development and is licensed to private players in the country to test and commercialise the vaccine. Today, nearly fifteen vaccine candidates for diseases such as Dengue, TB, Chikungunya, Influenza, Pneumococcal Disease, Cholera, Malaria and COVID-19, are in various stages of development with complete or partial support from the government.

Alongside financial models and funding, the Government of India employed a three-pronged strategy of building capacity through infrastructure support,[193] developing new and advanced vaccine candidates and enhancing product development and manufacturing capabilities.

Investments of the ICMR in setting up 144 regional, state level and medical college level labs through the Viral Diagnostic and Research Labs network have helped in early diagnosis of diseases in remote parts of the country by saving sample transportation requirements. Other initiatives include the setting up of agencies like BIRAC, which helped implement missions such as the National Biopharma Mission, in partnership with the World Bank, Ind-CEPI, in partnership with Coalition for Epidemic Preparedness (CEPI), and the Grand Challenges India partnership with the Bill & Melinda Gates Foundation. These missions supported infrastructure investments like shared Manufacturing and Analytical facilities, Clinical Trial Networks, Translational Research Consortia, Animal Testing Facilities, Biorepositories as well as provided grants and support to academia and industry to develop therapeutics and vaccine candidates. Laboratories and infrastructure investments were also made in the autonomous research institutions of the government.

International partnerships such as bilateral collaboration with National Institutes of Health (NIH), US through the Indo-US Vaccine Action Programme (VAP); cooperation with European Union through the Horizon 2020 Programme; Grand Challenges India and Ind-CEPI Mission, were fostered which have enabled strengthening of clinical trial sites, setting up of immunoassay laboratories, animal challenge facilities, development of harmonised protocols and enhancing manufacturing capabilities, thereby, fostering a conducive end-to-end vaccine development ecosystem. Clinical Trial Networks, which are collections of clinical trial sites with well-studied populations to conduct multi-centric trials, and reduce the time required to set up a clinical trial, have also been set up.

All these investments laid the foundation that allowed India to mount a cohesive and determined response to the COVID-19 pandemic.

The race for vaccines and vaccination against COVID-19

The COVID-19 pandemic brought to the front and centre the importance of vaccines and vaccine delivery systems at a scale that had not been seen for some time. In a race against time, and a mounting death rate, researchers and governments worked to bring out vaccines that would save lives against a disease that we did not know much about. Today, estimates show that just in the first year of the pandemic, vaccines resulted in a global reduction of 63% in total deaths and saved 19.8 million lives.[194]

In India, the response to the pandemic was a combined effort of scientific research excellence, regulatory easing without compromising on safety, and the use of the digital infrastructure expertise that the country already had.

The Government of India employed two approaches to the development of vaccines against COVID-19. One approach was to leverage India's expertise in vaccine development and the other was to leverage international science.

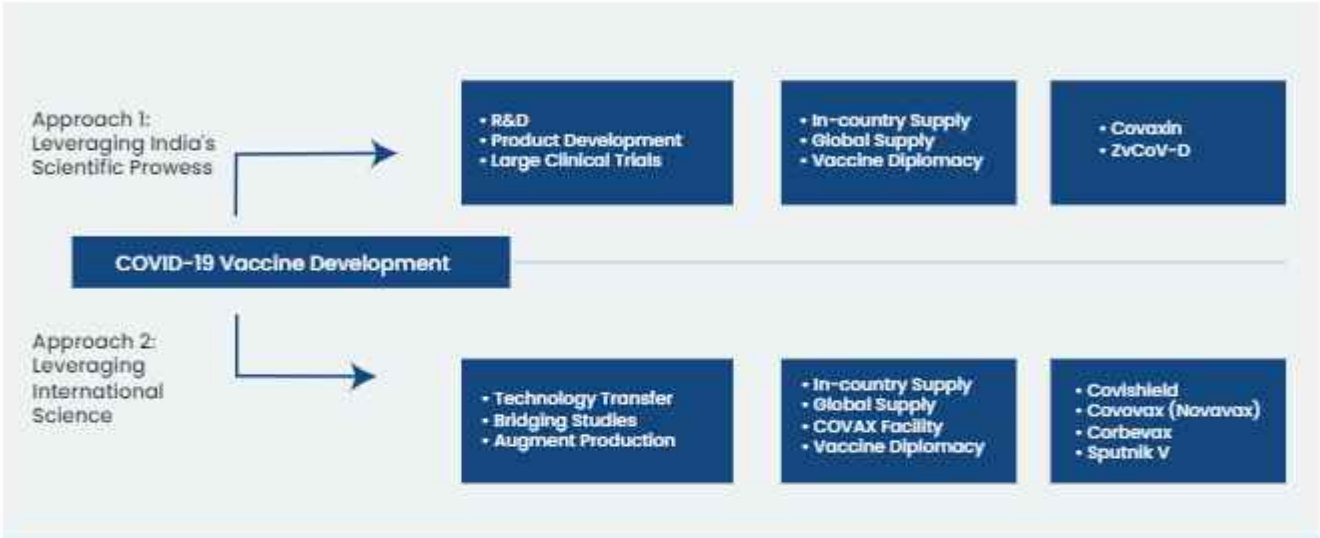


Figure 13: Approaches to the development of COVID-19 vaccines in India
(Source: Indian Council of Medical Research inputs)

To harness Indian expertise in vaccine development the GoI launched Mission COVID Suraksha, with an outlay of INR 900 crores under the Aatmanirbhar Bharat 3.0 package. The goal of the Mission was to accelerate the development of at least 5-6 COVID-19 vaccine candidates and ensure that some of these are brought closer to licensure and introduction in the market for consideration by regulatory authorities and for introduction in public health systems.

FACTSHEET

Year of Union Cabinet Approval	2020
Nodal Agency	Ministry of Science and Technology, Department of Biotechnology
Financial Outlay	INR 900 crores
Key Achievements	• Development of 4 vaccines against COVID-19 that have received Emergency Use Authorization, in India- GEMCOVAX, CORBEVAX, Zycov-D, INCOVACC. • Augmentation of domestic manufacturing capacity. • Five Animal Challenge Facilities and Six Clinical Immunogenicity Labs created • 19 Clinical Trial Sites Strengthened

The Mission's objectives were to:

- Accelerate pre-clinical & clinical development; licensure of COVID-19 vaccine candidates that are currently in clinical stages or ready to enter the clinical stage of development.
- Establish clinical trial sites, and strengthen the existing immunoassay laboratories, central labs and suitable facilities for animal studies, production facilities and other testing facilities to support COVID-19 vaccine development.
- Support training, and regulatory submissions, to accelerate clinical development and licensure of COVID-19 vaccine candidates that have targets identified.
- Support capabilities for process development, cell line development and manufacturing of Good Manufacturing Practice (GMP) batches for animal toxicology studies and clinical trials.
- Development of a suitable Target Product Profile so that vaccines being introduced through the Mission have preferred characteristics applicable to India.

Parallelly, the development of COVAXIN, the first COVID-19 vaccine was undertaken indigenously by the ICMR-National Institute of Virology (NIV) and Bharat Biotech International Limited (BBIL), isolating the virus from throat swabs of patients. The lab-to-market journey of Covaxin took approximately 8 months. COVAXIN has been the backbone of India's national COVID-19 vaccination drive, which became one of the world's largest vaccination drives, administering over 350 million doses. It has also received emergency use authorisation in 14 countries, including Mexico, Brazil, Nepal, and Iran.

Mission COVID Suraksha has led to the development of 4 vaccines against COVID-19 that have received Emergency Use Authorisation, in India. These are some of the world's firsts, such as the world's first DNA vaccine for COVID-19, ZyCoV-D; protein subunit vaccine, CORBEVAXTM (for use in 5 years & above); mRNA vaccine GEMCOVAC™-19; first intranasal COVID-19 Vaccine (iNCOVACC). CORBEVAXTM and iNCOVACC have also been approved as boosters.

Image 60: India's COVID-19 vaccine arsenal
(Source: ICMR and Department of Biotechnology inputs)

The Mission has also led to the development of indigenous mRNA[195] and DNA platforms for vaccine development.

The government has also invested in upgrading and augmenting domestic production capabilities of the Covid-19 vaccine for both the public and private sectors. Facility augmentation has been supported at Bharat Biotech, Indian Immunologicals and the Gujarat COVID vaccine consortium. Hamster and transgenic mice challenge models were developed and neutralization assays were standardized. Translational Health Science and Technological Institute (THSTI) facility provided animal models and immunoassay services to vaccine developers. Clinical trial sites established an electronic volunteer database with 150,000+ subjects.

Easing and supporting regulatory requirements

Apart from providing funding, the government played a central role in expediting regulatory processes that surround vaccine testing and manufacturing such as bridging trials of vaccines from abroad, which were then manufactured in India, for example Covishield.

Central Drug Standard Control Organisation (CDSCO) (under the Directorate General of Health Services, MoHFW) issued an order that vaccines against Covid-19 approved by specific countries such as the US, UK, Japan and others, or the World Health Organisation (WHO) no longer require post-approval bridging trials and batch testing in India. If the vaccine has been certified and released by the national control laboratory of certain countries or if it is listed in the WHO Emergency Use Listing (EUL), it was exempted from the requirement of localised clinical trials, mandating instead the requirement of post-approval parallel bridging studies.[196] This allowed vaccines to reach the market in an expedited manner. However, the study of the vaccine performance would continue for batch release as per standard procedures. This was a radical departure from the past allowing rapid and simplified authorisation of foreign vaccines by CDSCO.

Another policy easement, the Rapid Regulatory Response Framework notified by DBT,[197] laid down processes for the fast review of applications for the development of vaccines, diagnostics, prophylactic and therapeutics, and created checklists for Pre-clinical toxicity studies for recombinant vaccines. This increased the speed with which the industry was receiving feedback on clinical trial data and was, therefore, able to move the development process faster.

On the manufacturing side, the government allowed companies to commercially manufacture vaccines post successful Phase I clinical trials, to stockpile vaccines while Phase 2&3 clinical trials are ongoing.[198]

The indigenous production of the vaccines has enabled India to supply 14.8 million doses to over 100 countries worldwide as part of its 'Vaccine Maitri' scheme.

Scaling digital solutions to vaccinating India against Covid-19[199]

CoWIN, or the COVID-19 Vaccine Intelligence Network, was born out of Indian ingenuity, expertise in digital solutions, and the need to provide, record and certify vaccinations for a population of over 1 billion people.

The country's experience with eVIN and developing and scaling Aadhaar and UPI, allowed the development of an end-to-end digital solution which served the function of registration, appointment scheduling, identity verification, vaccine status with inventory databases, vaccination, and verification of the vaccination. Digital Infrastructure for Vaccination Open Credentialing (DIVOC) was created as an open-source digital platform to help with the rapid rollout of digital credentials such as vaccine certificates and post-vaccination feedback.

The platform was also integrated with biometric digital identity tools such as Aadhaar and DigiLocker. It has its own API policy which helps seamless integration with third-party apps for ease of use.

Image 61: The CoWIN portal *(Source: CoWIN website)*

As on 24th June 2023, the total number of vaccination doses administered to date is over 220 crores.[200]

Conclusion

India's history with vaccines is a story of novel interventions, pushing frontiers, citizen impact and aligning with national priorities. Collaboration, leveraging expertise, dedicated investment and policy support have all contributed to propelling the country as one of the largest vaccine manufacturers in the world.

India has the potential to further scale up and strengthen the vaccine development and delivery ecosystem for the country and the world. With consistent investments in research, capacity and infrastructure, and by fostering strong collaborations and partnerships, India can be a global leader in the area of vaccine development and vaccine provider.

A NOTE

Over the past decade, India has experienced remarkable progress and significant growth. During this time, we have observed India's emergence as a formidable presence in the field of S&T, marked by a plethora of ambitious achievements and groundbreaking initiatives. This report endeavors to highlight a select few of these remarkable endeavors, shedding light on the exceptional contributions made by our country's formidable scientific community. Nevertheless, it is essential to acknowledge that this report offers just a glimpse of the extraordinary work that has unfolded in India. Countless missions, achievements, and programs have taken shape, far exceeding the scope of what we could encompass within these pages.

END NOTES

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