विज्ञान एवं प्रौद्योगिकी विभाग
DEPARTMENT OF
SCIENCE & TECHNOLOGY
सत्यमेव जयते

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DREAM 2047

Major National Scientific Missions & Programmes

The Strategic Vision Shaping India's Scientific Future

विज्ञान एवं प्रौद्योगिकी विभाग
DEPARTMENT OF
SCIENCE & TECHNOLOGY

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Minister of State in the Department of Space
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MESSAGE

National scientific missions are transforming the way Bharat addresses complex challenges and creates opportunities for sustainable growth. Designed to integrate research, innovation, technology development, industry, and societal needs, these missions represent a strategic investment in the nation's future. They are not only advancing scientific frontiers but are also building capabilities that strengthen economic development, environmental sustainability, technological self-reliance, and global competitiveness.

The strength of these missions lies in their collaborative approach. They bring together government, academia, research institutions, industry, start-ups, and international partners to accelerate the development and deployment of technologies that can make a meaningful difference to society. Whether in artificial intelligence, clean energy, climate resilience, biotechnology, Earth system sciences, space exploration, or emerging technologies, these initiatives are creating an ecosystem where scientific knowledge is translated into practical solutions with far-reaching impact.

Equally important is the opportunity these missions create for our young people. Students, researchers, engineers, innovators, and entrepreneurs are central to this national endeavour. Through access to world-class research facilities, collaborative platforms, innovation support, fellowships, technology development programmes, and global partnerships, they are encouraged to contribute to scientific discovery and develop solutions to future challenges. Their ideas, creativity, and enterprise will determine the pace and direction of India's scientific and technological progress.

This issue of Dream 2047 titled 'Major National Scientific Missions and Programmes' presents a selection of major national scientific missions and programmes that illustrate the diversity and dynamism of India's science, technology, and innovation ecosystem. The articles highlight initiatives that are expanding the frontiers of knowledge while creating pathways for innovation, entrepreneurship, and international collaboration. Together, they demonstrate how mission-driven science can contribute to national development and improve citizens' lives.

I congratulate the editorial team for curating this timely issue and hope it inspires readers, particularly young minds, to explore the opportunities these national missions offer.

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Secretary
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Department of Science and Technology

17th July, 2026

Foreword

The vision of Viksit Bharat @2047 rests on the conviction that science, technology and innovation will be among the foremost drivers of India's journey towards becoming a developed, self-reliant and globally competitive nation. Addressing the complex challenges of the twenty-first century, ranging from climate change and energy security to sustainable industrial growth, food and health security, disaster resilience and strategic technologies, requires a coordinated, mission-oriented approach that harnesses the collective strengths of government, academia, research institutions, industry and start-ups.

India's major national scientific missions and flagship programmes exemplify this whole-of-government approach. Spearheaded by diverse ministries, departments and scientific agencies, these initiatives are accelerating scientific discovery, promoting indigenous technology development and translating research into solutions that improve lives and strengthen national capability. Whether it is nurturing a sustainable bioeconomy through BioE3, advancing carbon capture, utilization and storage technologies, supporting India's clean energy transition, strengthening climate and Earth system science through the PRITHVI programme, unlocking the potential of high-value aromatic crops through the Aroma Mission, expanding the frontiers of solar exploration through Aditya-L1, or catalysing excellence in research and innovation through the Anusandhan National Research Foundation (ANRF), these missions collectively reflect India's commitment to science-led, sustainable and inclusive development. Together, these initiatives exemplify the Government of India's whole-of-government approach to science, technology and innovation, bringing together the Department of Science and Technology, Department of Biotechnology, Council of Scientific and Industrial Research, Department of Space, Ministry of Earth Sciences, the ANRF and several other scientific institutions in pursuit of shared national goals. By enabling convergence across disciplines, institutions and sectors, they are laying the foundation for technological leadership, economic resilience and sustainable development.

This issue of Dream 2047 presents a thoughtful compilation of these transformative missions and programmes, highlighting their scientific significance, societal relevance and potential to shape India's future. It emphasises the importance of interdisciplinary research, institutional collaboration and innovation-driven policymaking in addressing national priorities and contributing to global scientific progress.

I congratulate the Editorial Board for bringing out this timely and insightful issue and sincerely appreciate all the authors and contributors for sharing their knowledge and expertise. I am confident that this publication will promote a deeper understanding of India's scientific endeavours, stimulate informed dialogue across the scientific community and beyond, and inspire researchers, innovators and young minds to contribute to the nation's enduring quest for knowledge, innovation and sustainable development.

V. Umesh

(Umesh V. Waghmare)

FROM THE CHIEF EDITOR'S DESK

Smt. A. Dhanalakshmi

Joint Secretary
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Science, technology, and innovation are central to India's aspiration of becoming a developed Nation by 2047. Guided by a clear vision and sustained investments in research, innovation, and human resource development, India is making significant progress across diverse scientific domains. Mission-driven programmes, cutting-edge research, and international collaborations are advancing scientific knowledge while contributing to economic growth, environmental sustainability, societal well-being, and national self-reliance. This issue of Dream 2047 presents a glimpse of some of the major scientific missions and programmes shaping India's scientific and technological landscape.

India's scientific ecosystem reflects a strong commitment to addressing national priorities while contributing to global scientific progress. Flagship initiatives of the Department of Science and Technology (DST), Department of Biotechnology (DBT), Council of Scientific and Industrial Research (CSIR), Ministry of Earth Sciences (MoES), and the Department of Space (DoS) demonstrate how science and technology are driving innovation and sustainable development.

Among the important initiatives featured in this issue is BioE3 (Biotechnology for Economy, Environment and Employment), which seeks to harness biotechnology for sustainable economic growth, environmental conservation, and employment generation. The National Green Hydrogen Mission aims to position India as a global leader in clean hydrogen production while accelerating the transition to a low-carbon economy. Emerging technologies such as Carbon Capture, Utilisation and Storage (CCUS) also hold great promise in reducing industrial carbon emissions and supporting India's climate goals.

India's achievements in space science continue to inspire the nation. The success of Aditya-L1, India's first dedicated solar mission, marks another milestone in space exploration and solar research. Equally significant is YUVIKA (YUva VIgyani KAryakram), which nurtures scientific curiosity among school students and encourages them to pursue careers in science, technology, engineering, and innovation.

The issue also highlights the PRITHVI Scheme of the Ministry of Earth Sciences, which integrates research in weather, climate, oceans, seismology, and polar sciences to strengthen forecasting systems and disaster preparedness. As climate change presents increasing challenges, advances in earth system science and environmental monitoring are becoming indispensable for sustainable development and national resilience.

Recognising the importance of global cooperation, this issue also features India's expanding scientific partnerships with countries such as Germany and the United States. These collaborations promote joint research, innovation, technology development, and capacity building while strengthening India's research ecosystem and contributing to solutions for global challenges.

As India progresses towards the vision of Viksit Bharat 2047, science, technology, and innovation will remain the cornerstone of national development. Equally important is the effective dissemination of scientific knowledge that informs, inspires, and engages researchers, students, policymakers, industry, and the public. Through this issue, we aim to present these missions and programmes in an accessible manner while highlighting their contribution to India's developmental journey.

This issue covers some of the major scientific missions, schemes, and programmes being implemented by the country's scientific Ministries and Departments. Owing to space constraints, it has not been possible to include every important initiative in a single issue. We propose to feature many more flagship programmes, emerging scientific missions, pioneering technologies, and notable achievements in forthcoming issues of Dream 2047, thereby providing our readers with a broader and more comprehensive perspective on India's vibrant and rapidly evolving science, technology, and innovation ecosystem.

EDITOR'S NOTE

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Bharat's scientific landscape is witnessing remarkable momentum as a wide range of national missions, programmes, technological innovations, and international collaborations drive the country's progress towards 2047. From artificial intelligence, quantum technologies, biotechnology, clean energy, advanced manufacturing, agriculture, and high-performance computing to space exploration and strategic research, these initiatives reflect a sustained national commitment to advancing scientific excellence, developing indigenous technologies, addressing societal challenges, and creating new opportunities for innovation-led growth. Together, they are not only strengthening India's research and innovation capabilities but also laying the foundation for a more resilient, self-reliant, and knowledge-driven future.

This issue of Dream 2047 brings together a selection of these initiatives. While it is impossible to capture the entire breadth of India's scientific enterprise in a single issue, the articles presented here offer a glimpse of the ideas, institutions, and missions that are transforming science into societal impact. Several other important programmes and national missions will be featured in future issues.

The issue begins with the CSIR Aroma Mission, a compelling example of how scientific research can improve livelihoods by promoting aromatic crop cultivation and rural entrepreneurship. It is followed by the BioE3 Policy, which outlines India's vision for biomanufacturing and a bio-based economy, bringing together biology, engineering, and digital technologies to create new opportunities in healthcare, agriculture, industry, and environmental sustainability.

India's growing capabilities in space science are represented through Aditya-L1, the country's first dedicated solar observatory, while YUVIKA (YUva VIgyani KAryakram) shows how early exposure to science can inspire the next generation of researchers and engineers. The article on the Seaweed Mission highlights another emerging area where marine resources, biotechnology, and sustainable development come together to create new opportunities for coastal communities and industry.

The transition to cleaner energy forms another important theme of this issue. Articles on the Energy Transition, Carbon Capture, Utilisation and Storage (CCUS), and the National Green Hydrogen Mission explore the technologies and policies that are helping India reduce carbon emissions while building a more sustainable future.

The issue also looks at the institutions and partnerships that connect research with real-world applications. The Technology Development Board has played an important role in helping indigenous technologies move from laboratories to the marketplace. International collaborations through the Indo-German Science and Technology Centre and the Indo-U.S. Science and Technology Forum continue to bring together researchers, universities, and industry to address shared scientific challenges. Complementing these is the article on Good Laboratory Practices (GLP), which highlights the importance of quality and reliability in scientific research.

The stories in these pages are not only about missions and programmes; they are also about the opportunities they create. Whether in a laboratory, a start-up, a university, or a research field station, science offers countless ways to contribute. We hope this issue encourages readers to explore these opportunities, discover new areas of interest, and see themselves as participants in India's scientific journey. Perhaps a future edition of Dream 2047 will tell the story of a breakthrough that begins with one of today's curious young minds.

Cultivating Aromas of Success

CSIR-Aroma Mission Journey Towards Self-Reliance in Essential Oils and Sustainable Agriculture

Dr Prabodh Kumar Trivedi

Mission Director, CSIR Aroma Mission
Director, CSIR-CIMAP

Dr N Kalaiselvi

Director General, CSIR
Secretary, DSIR

The growing global demand for natural essential oils and herbal products prompted the Government of India to launch an aroma mission in 2017. This initiative, spearheaded by leading laboratories under the Council of Scientific and Industrial Research (CSIR), Ministry of Science and Technology, has completed three phases. The mission's overarching objectives included producing high-quality essential oils, ensuring sustainability, adding value to products, creating employment opportunities, and enhancing farmers' incomes. Team–Aroma Mission CSIR, led by CSIR-CIMAP as the nodal lab and associated CSIR labs, made exceptional contributions in developing high-yielding varieties of aromatic crops, promoting and popularising them among farmers, ultimately enhancing farmers' income and ensuring a stable livelihood for the targeted farmer groups through consistent technical support. The teams' efforts have significantly transformed the rural economy, reshaped market dynamics, created excellent growth opportunities within the aromatic oil sector, and provided comprehensive technologies and process solutions across the country, thereby encouraging rural entrepreneurship, empowering rural women, and fostering employment in rural areas. The mission has been implemented in a phased manner by CSIR institutes, and in every phase has had a specific focus, such as scientific intervention at farmers' fields, knowledge dissemination, deployment of technologies, improvement in infrastructure, capacity building, entrepreneurship development, start-up creation, and value addition.

AI-Generated image

Phase I (2017–2020)

Foundation Building through Technology Introduction and Awareness

The first phase of the CSIR-Aroma Mission laid the groundwork for transforming India's aromatic crop sector by introducing high-yielding and superior chemotype varieties to replace obsolete genotypes. Emphasis was placed on the multiplication and dissemination of quality planting material directly in farmers' fields, ensuring rapid adoption. Scientific efforts focused on the identification of elite genotypes with enhanced essential oil yield and quality, along with the development of robust agro-technologies tailored for higher productivity. Simultaneously, outdated distillation systems were replaced with improved processing units to enhance oil recovery and quality, including the fractionation of desirable compounds. Recognising the limited awareness among farmers and stakeholders, extensive outreach and capacity-building programmes were conducted. These initiatives played a critical role in sensitising rural communities to the economic potential of aromatic crops, thereby initiating diversification toward high-value agriculture.

Phase II (2020–2023)

Expansion, Value Chain Strengthening, and Rural Industrialisation

The second phase focused on scaling up the cultivation of aromatic crops to meet growing domestic and industrial demand. Expansion into underutilised and degraded lands was prioritised, supported by the deployment of high-yielding varieties suited to stress-prone environments. A key shift during this phase was the farmer-led multiplication of planting material, enhancing self-reliance and sustainability. Region- and environment-specific agro-technologies were further refined to maximise productivity across diverse agro-climatic zones. The mission promoted the installation of low-cost, fuel-efficient distillation units to improve processing efficiency and reduce emissions and operational costs. Importantly, this phase emphasised value addition and rural industrialisation by encouraging cottage-based enterprises and small-scale industries centred on essential oils and their derivatives. Training programmes were extensively conducted on cultivation, processing, and quality assurance, including ensuring the safety and standardisation of essential oils. These efforts collectively strengthened the value chain, improved market linkages, and enhanced farmers' income.

Phase III (2023–2026)

Sustainability, Innovation, and Global Competitiveness

The third phase was strategically oriented toward positioning India as a global leader in the aroma sector while ensuring sustainability and technological advancement. Priority was given to high-potential export-oriented crops and those capable of reducing import dependency. The mission advanced the development and deployment of socially, economically, and environmentally sustainable agri- and processing technologies. A major thrust is on establishing model aroma clusters that integrate cultivation, processing, and value addition within a localised ecosystem. Efforts included developing climate-resilient, resource-efficient varieties supported by genomic resource development, alongside the adoption of precision agriculture techniques. Processing innovations such as optimised distillation systems, renewable energy-based units, and microwave-assisted extraction technologies are being promoted to enhance efficiency and sustainability. Quality assurance was strengthened through rapid analytical tools for essential oil profiling and the detection of adulterants, including synthetic compounds, supported by the development of pure reference materials. The mission also expanded into high-value product development for human and veterinary applications, ensuring safety through GLP-compliant toxicity evaluations. In addition, waste-to-wealth approaches such as the valorisation of de-oiled biomass and the utilisation of hydrosols for flavours and fragrances were emphasised. Digital transformation was integrated through interactive portals and mobile applications for agro-advisory services and market intelligence. Skill development programmes with a strong focus on entrepreneurship are enabling the creation of a vibrant, self-sustaining aroma-based economy.

Overall Societal and Economic Impact

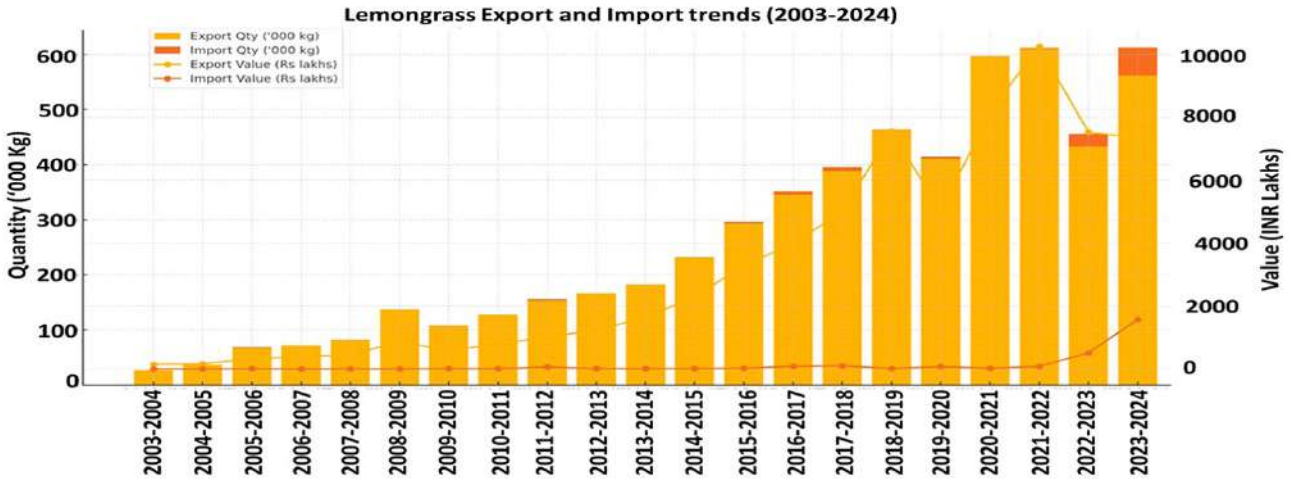
Across its three phases, the CSIR-Aroma Mission has matured into a nationally transformative model of science-driven rural development, seamlessly integrating cutting-edge research with grassroots implementation and industry partnerships. By aligning innovation with farmer-centric interventions, the mission has delivered measurable gains in income enhancement, large-scale employment generation, import substitution, and export promotion, directly contributing to India's vision of an Atmanirbhar Bharat in the aroma sector. Participating CSIR laboratories have played a pivotal role in strengthening the entire aroma value chain, from the development of high-yielding, chemotype-specific varieties to efficient essential oil extraction and the valorisation of biomass into high-value products. The mission's strong emphasis on waste-to-wealth approaches has enabled the conversion of de-oiled residues into commercially valuable derivatives, enhancing resource-use efficiency and industrial relevance. At the same time, focused efforts on quality assurance and standardisation have ensured that Indian essential oils meet global benchmarks.

A defining achievement of the mission has been its success in import substitution, enabling India to achieve self-reliance in several essential oils. The country has not only reduced dependence on imports but has also emerged as a leading global producer and exporter of key oils such as lemongrass. Region-specific interventions have further amplified impact. Lavender cultivation in Jammu has created a new agri-economy and expanded to the North-East, including Meghalaya. At the same time, Himachal Pradesh has emerged as a major hub for marigold essential oil production.

Lavender cultivation, known as the "Purple Revolution," is transforming agriculture in Jammu and Kashmir, specifically in the Doda, Kishtwar, and Ramban districts. The Council of Scientific and Industrial Research (CSIR) featured a tableau on India's "Purple Revolution" under the CSIR-Aroma Mission during the Republic Day parade on January 26, 2024, highlighting lavender cultivation in Jammu and Kashmir to showcase advancements in aromatic farming

The mission's inclusive approach is evident in the establishment of over 20 tribal aroma clusters, which have created sustainable livelihoods in remote, underdeveloped regions. By promoting cultivation on rain-fed, marginal, and degraded lands, the initiative has brought more than 51,000 hectares under aromatic crops through more than 4,500 farmer clusters, focusing on high-value species such as lemongrass, geranium, lavender, rose, citronella, and vetiver. Key technological interventions include the development and deployment of improved agro-technologies (>80), the development of elite varieties (>50), the production of value-added products (66), and the installation of over 400 advanced distillation units, all of which significantly enhance productivity and oil recovery. Capacity building has been a cornerstone, with more than 2,000 training programmes benefiting over 1.25 lakh farmers, entrepreneurs, and stakeholders. These activities led to the development of more than 120 entrepreneurs in aromatic crops and essential oils. Collectively, these efforts have enabled the production of 5,000–8,000 tonnes of essential oils and value-added products, contributing an estimated ₹1,500 crore to the aroma industry and national economy, while generating close to one crore rural employment opportunities.

The mission has generated a comprehensive knowledge base by advancing genomic resources for key medicinal and aromatic plants, elucidating the biosynthetic pathways of commercially important molecules, and developing strategies for resource-efficient, climate-resilient crops aligned with the Sustainable Development Goals. These efforts have strengthened the scientific foundation for next-generation aroma-based agriculture and industry. The CSIR-Aroma team has made significant contributions to knowledge dissemination and innovation, with more than 200 high-impact research publications and approximately 13 patents focused on process development, value addition, and technology optimisation. In recognition of these outstanding achievements and the mission's transformative national impact, the CSIR-Aroma



Increase in lemongrass export, cultivation in tribal settlement and interaction of tribal women farmers with the Director General, CSIR in Anamalai Tiger Reserve forest

team was conferred the prestigious Rashtriya Vigyan Puraskar (Vigyan Team Award)–2025, underscoring its excellence in translational research and societal benefit. The CSIR-Aroma Mission thus stands as a benchmark initiative, demonstrating how science, sustainability, and socio-economic empowerment can converge to reshape India's agricultural and industrial landscape.

Future Roadmap of the CSIR-Aroma Mission: Towards Global Leadership and Inclusive Growth

Building on the strong foundation established across its three phases, the CSIR-Aroma Mission is poised to enter a transformative phase that integrates sustainability, advanced technologies, and market-driven innovation to position India as a global leader in the aroma sector. The future roadmap envisions a holistic, end-to-end ecosystem that empowers farmers, promotes rural entrepreneurship, especially among women, and strengthens India's footprint in global essential oil markets. A central priority will be expanding aromatic crop cultivation by an additional 10,000 hectares, particularly in climate-affected, rain-fed, and underutilised regions. This expansion will be supported by sustainable, environmentally friendly cultivation practices that ensure optimal resource use, soil health, and resilience to climate variability. Parallel efforts will focus on developing region-specific, climate-resilient varieties to maximise productivity and returns.

To achieve global leadership in high-demand essential oils such as vetiver and palmarosa, the mission will integrate advanced breeding, genomic resource development, and precision agriculture. A comprehensive national database of genomic resources and reference aroma molecules will be established to support research, quality assurance, and product standardisation. A major thrust will be on Technology-Enabled Model Sustainable Aroma Clusters, which will serve as demonstration hubs for end-to-end solutions, from cultivation to processing, value addition, and marketing.

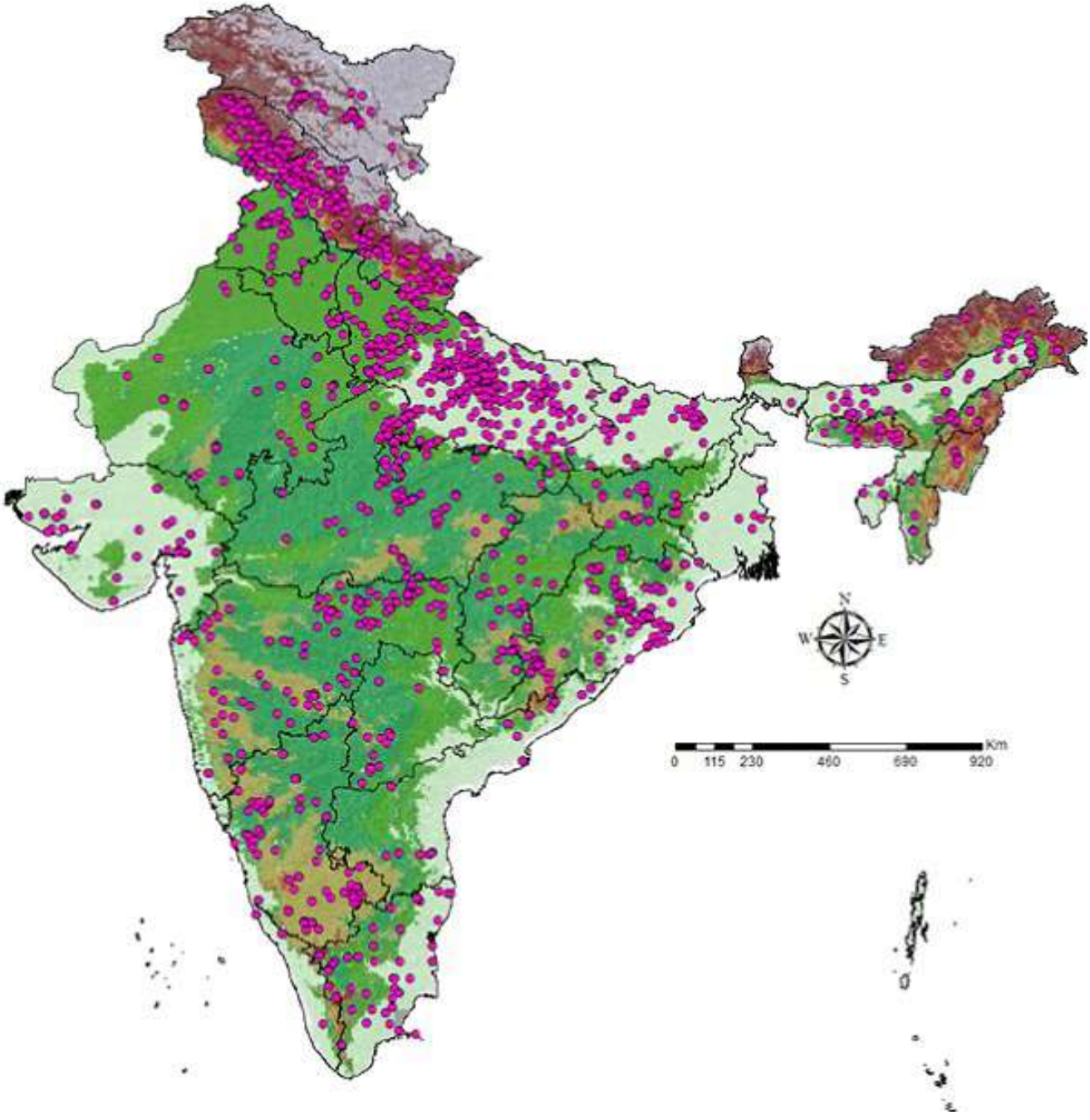
These clusters will act as incubation platforms, providing handholding support to farmers, women entrepreneurs, and start-ups, thereby accelerating rural enterprise development and strengthening cottage industries. Innovation in processing will be driven by the design and deployment of energy-efficient, renewable energy-powered distillation units, including next-generation systems for improved oil recovery and reduced environmental footprint. Simultaneously, waste valorisation strategies will be scaled up, converting distillation residues and hydrosols into high-value products for use in flavours, fragrances, nutraceuticals, and therapeutics, advancing a circular bioeconomy.

The mission will also prioritise the development of rapid, field-deployable tools for assessing essential oil quality and detecting adulteration, ensuring authenticity and global competitiveness. Strengthening value addition and product diversification will support

End-to-end technological support-an integral part of CSIR Aroma Mission

entrepreneurship and start-up ecosystems, particularly in rural and semi-urban areas. From a market perspective, the roadmap emphasises reducing import dependency while enhancing exports, supported by strategic branding and global outreach under the "CSIR Aroma" label. Efforts will focus on accessing international markets, establishing quality benchmarks, and ensuring fair and remunerative pricing for farmers. Finally, the mission will deepen collaborations with key stakeholders, including the Indian Council of Agricultural Research, industry partners, and global institutions, to enhance technology dissemination, value chain integration, and market expansion.

Aroma crops in different agro-climatic zones (A) and location of more than 4500 aroma clusters developed under CSIR-Aroma Mission



BIO-VISION FOR VIKSIT BHARAT

Dr Rajesh S Gokhale

Secretary
Department of Biotechnology
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Bioeconomy is a knowledge-economy driven by Biotechnology research and innovation. It holds the potential to catapult the nation's growth trajectory into a developed economy ensuring inclusive and sustainable progress. Propelling a green-technology bio-revolution and building new institutional frameworks for shared scientific goals are the key strategies. We envision the bioeconomy to grow to $ 300 + Bn and contribute to 5-6% of GDP. We aim to achieve this by catalyzing a green economic growth through new manufacturing paradigms driven by Biotechnology – Biomanufacturing.

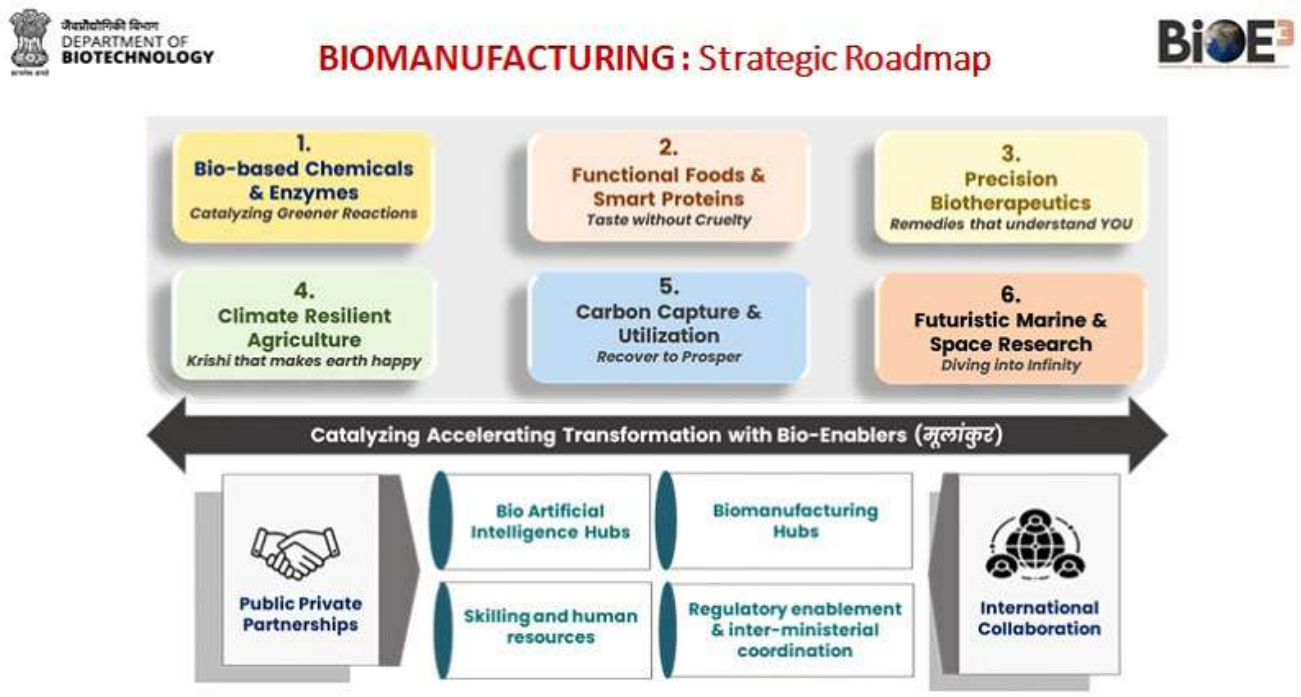
Petrochemicals to Bioinspired Innovations

Throughout various stages of evolution, human needs have been largely met from nature, be it food, water, clothing, shelter, medicines, fuel, materials. However nature could not meet the scale and demands of the rising human population. This drove the shift to petro- based industrial processes for production at scale. As a result, today, over 40 billion tons of CO2 is emitted into atmosphere contributing to climate change and producing long-term health and environmental damages. The world is now looking for bio-inspired innovations to propel the economies while advancing sustainability, reducing energy and material consumption.

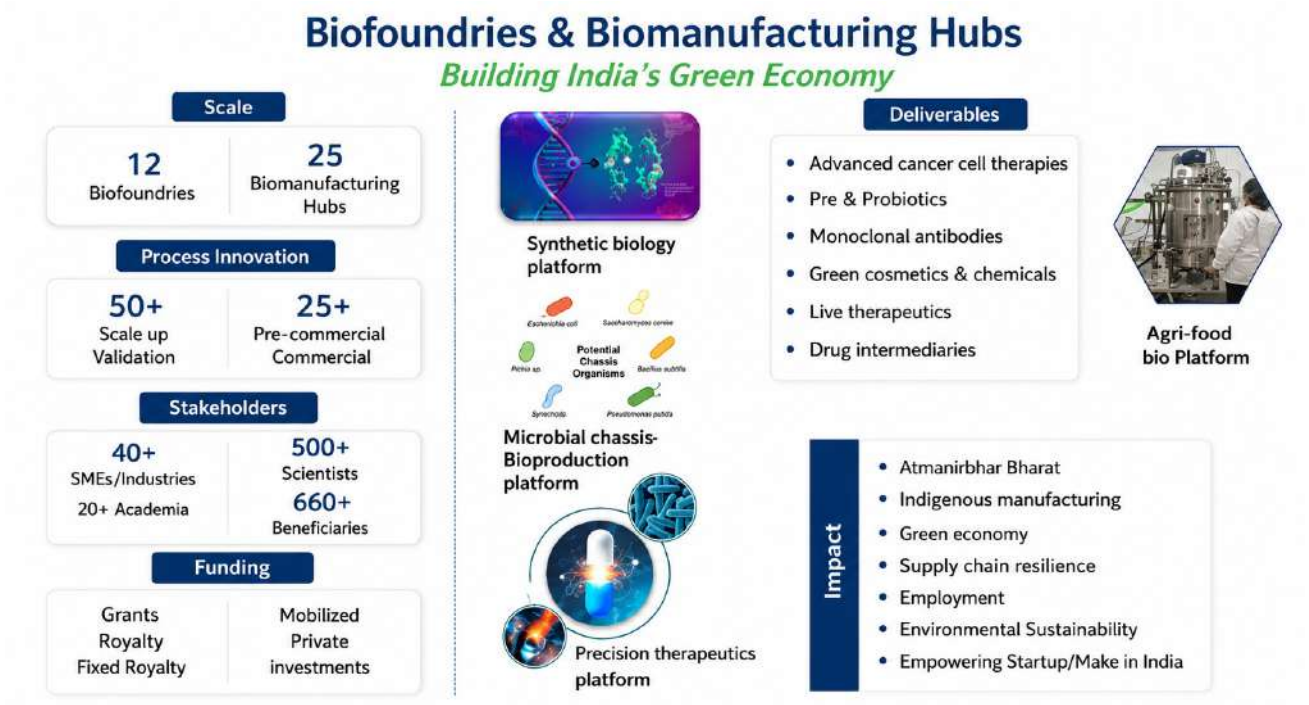
Biomanufacturing provides a viable opportunity for a green production technology replacing traditional chemical synthesis and hazardous industrial processes in almost all domains. This technology relies hugely on engineering the invisible tiny microbes and human or animal cells/cell-free systems to produce new solutions and products. Deep tech innovations originating at the convergence of genomics, synthetic biology, metabolic engineering, AI, precision fermentation coupled to enhanced speed of DBTL cycles of the biofoundries holds the key for transition of the cells and tiny creatures into biofactories.

BioE3 Policy

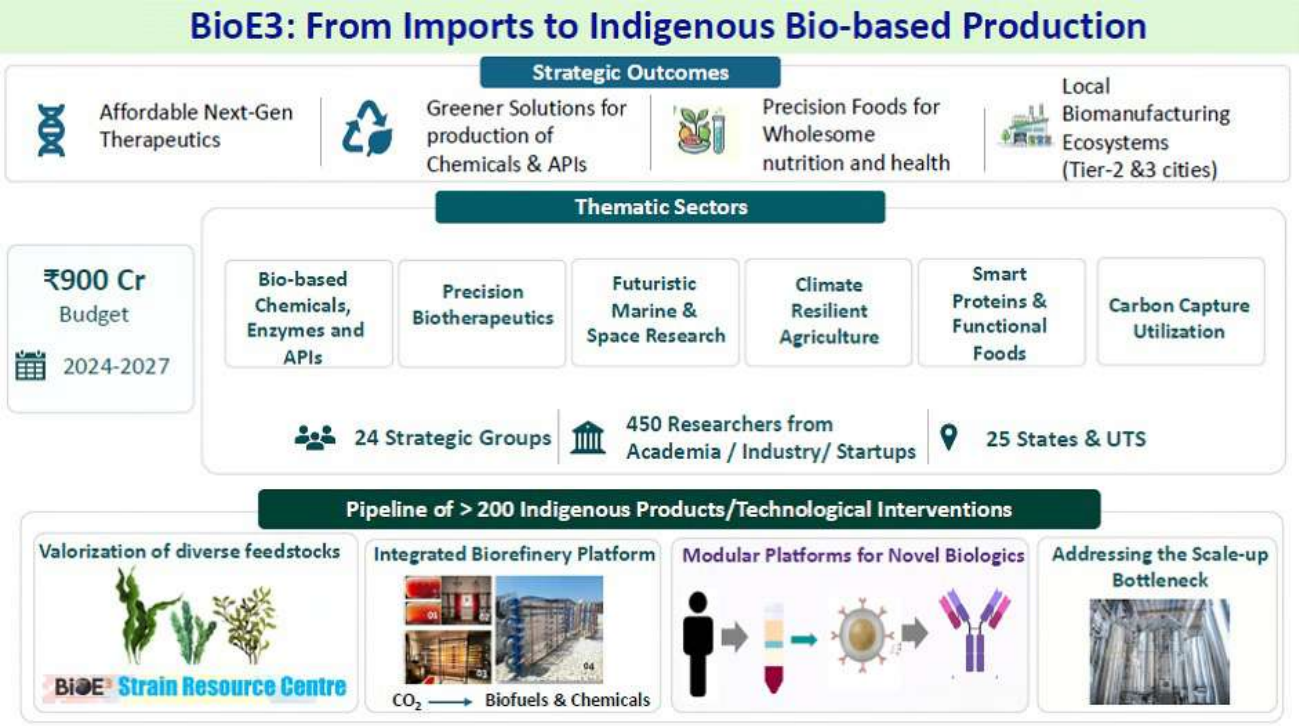
The Department of Biotechnology (DBT), Government of India, with the approval of the Cabinet launched the BioE3 policy to catapult this transition. The Policy is formulated and being implemented by DBT jointly with its PSU Biotechnology Industry Research Assistance Council (BIRAC) BioE3 Policy for a green, clean, prosperous, and self-reliant India empowers Indian institutions and industries to engage in transformative innovation through Public-Private Partnership (PPP) and international collaborations.



Several Biofoundries, Biomanufacturing hubs are being established across the country as Bioenablers forming the key backbone of this initiative to enable start-ups, SMEs, industries and academia with access to shared infrastructure/facilities and resources for pilot and pre-commercial scale biomanufacturing of bio-based products. Bio-AI hubs, one of the enablers for building data-driven, cutting-edge, programmatic research support for the Biomanufacturing initiative provides critical and novel research leads impacting Health, Agriculture and Environment.



India's first Biofoundry network a landmark initiative aimed at transforming the country's biotechnology landscape serving as a national platform to support bioproduction scale-up at academia has been launched as a first set of implementation. It also brings together 15 cutting-edge Biomanufacturing Platforms mostly at industry and industry-academia facilities across India, offering shared infrastructure to start-ups, SMEs, industries, and academic institutions. These centers will support pilot and pre-commercial scale up of technologies across diverse sectors, including microbial biomanufacturing, sustainable agriculture, smart proteins, functional foods, precision biotherapeutics, marine biotechnology, carbon capture, and next-generation cell and gene therapies.



In addition, several discovery and bridging the gap research programs are being undertaken in the six thematic verticals envisioned.

- **Bio-based chemicals, Active Pharmaceutical Ingredients (APIs), and Enzymes**
- **Functional Foods and Smart Proteins**
- **Precision Biotherapeutics (monoclonal antibodies, mRNA therapeutics, cell & gene therapy)**
- **Climate resilient agriculture (agribiologicals)**
- **Biofuels and Carbon capture**
- **Futuristic marine and space research**

Reimagining Food, Health & Materials

Agriculture is the backbone of Indian economy contributing to around 18% of the GDP and over 50% of the population employed in Agri and allied sectors impacting livelihoods. The major contributor to agricultural productivity and our food security is nitrogenous fertilizers which also leads to green house gas emissions, air pollution, potable water contamination, biodiversity loss. India is the second largest consumer of nitrogenous fertilizers globally with 19.44 million metric tons. Biomanufacturing of engineered/genetically-edited microbes have started replacing fertilizers in cereal productions. Transgenic crops developed through molecular breeding and marker-assisted selections had delivered biotic/abiotic stress resilient crops, improved yields and harvest

without synthetic chemicals and pesticides in addition to our continued efforts on gene edited and GM crops. Livestock production uses 77% of all agricultural land (FAO, 2020) and deforestation is rapidly increasing globally reducing nature's carbon capture ability for making more land for farming. Cultivated meat, a new food-technology based on biomanufacturing of animal cells is already a reality in countries like Singapore and is under approvals in the US.

Precision biotherapeutics are transforming healthcare by enabling highly targeted, personalized treatments tailored to an individual's genetic profile, lifestyle, and disease characteristics, with significant potential for cancer, autoimmune disorders, and rare genetic diseases. In India, advances in genomics, biotechnology, digital health, and Artificial Intelligence are accelerating the development of safer, more effective, and scalable therapies, particularly in mRNA therapeutics, monoclonal antibodies (mAbs), and Cell and Gene Therapies (CGTs). The versatile mRNA platform, proven during the COVID-19 pandemic, is expanding into cancer, infectious diseases, genetic disorders, and gene editing, supported by growing indigenous capabilities in nanobiotechnology and biomanufacturing. mAbs continue to be a cornerstone of precision medicine for oncology, autoimmune diseases, and emerging infections, with India strengthening its position through biosimilars. CGTs, which directly address the genetic and molecular causes of disease, represent the next frontier of therapeutic innovation. DBT-supported programmes, such as the National Biopharma Mission (NBM), have substantially strengthened India's capabilities in these emerging therapies by supporting translational research, technology platforms, GMP manufacturing, and industry–academia collaborations. These efforts have enabled the development of indigenous biologics and advanced therapeutics, including India's first homegrown CAR-T cell therapy (NexCAR19) and has established a pipeline for more.

The bulk of materials used extensively in healthcare, personal care, clothing, construction and transportation are petrochemical-based raw materials such as wax, plastics, nylon, polyesters or extracted from animals/plants with poor scalability – collagen, cellulose, hyaluronic acid etc. Biosynthesis of biodegradable biomaterials and their sustainable manufacturing is the potential of biomanufacturing. For instance globally around 390 Mn tonnes of plastic is produced and India is the largest importer.

The utility of plastics is across sectors- from disposables to medical devices, packaging, automotive, cosmetics etc. In this, only less than 1% (about 2.2 Mn tonnes) is only biodegradable plastics setting the top priority for bioplastics biomanufacturing.

Biofuels provide renewable alternative for achieving the global climate change targets of net zero by 2050 especially for hard-to electrify sectors. First gen (1G) biofuels are produced by microbial fermentation of edible feedstocks and accounts for most of the bioenergy produced today. With the on-going debated on food vs fuel security, 2G biofuels based on lignocellulosic biomass from residues is being researched extensively.3 G and 4G biofuels based on microalgae & cyanobacteria biomass and engineered microbes respectively are emerging research frontiers. India has achieved 10% ethanol blending and has a roadmap for 20% by 2025. Policy to incentivize 2G /3G/4G biofuels will help accelerate the bioenergy biomanufacturing without compromising on agricultural productivity for food.

Department of Bold Transformation (DBT)

Pursuing with our ambitious targets for research and innovation in Biotechnology, this pioneering policy is being implemented to reimagine food, health, fuel and environment in a bio-way employing living systems as factories for ensuring sustainability. We are working with various stakeholders across academia, industry, start-ups to build a green planet in which there would be milk without cows, fuels without crude oil, green chemicals, meat without slaughter, medicines tailored to individuals, chronic ailments being cured, plants edited to make them climate-smart and nutritious and reaching out to space for novel biotech experiments.

Leapfrog, Not Incremental

Inside ANRF's Big Bet on India's 2047 Ambitions

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Dr Shivkumar Kalyanaraman

Chief Executive Officer
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Government of India

The Space Between "It Works" and "It Works for India"

Every year, Indian laboratories publish thousands of promising results — a cheaper solar cell, a faster diagnostic kit, a hardier crop variety, a smarter irrigation sensor. And every year, only a tiny fraction of these ideas ever reach the people they were meant to help. The problem is rarely the science itself. It is the long, unglamorous, often underfunded journey from "this works in a controlled lab" to "this works on a farm in Bundelkhand, in a slum in Surat, or on a highway in the monsoon."

This gap has a name in India's development conversations: the valley of death between research and real-world deployment. It is where good ideas quietly stall — validated at small scale, admired in journals, and never adopted at the scale that would actually move a national indicator.

As India works toward its Viksit Bharat vision for its centenary year of independence in 2047, this gap is no longer just an academic inconvenience, it is a bottleneck standing between the country's research capacity and its development goals. Bridging it will decide whether

Somewhere between a laboratory bench and a village field lies the hardest problem in Indian science — not discovering something new, but making it work at the scale of a billion people. A new programme from the Anusandhan National Research Foundation wants to close that gap, on purpose, and fast.

India's next twenty-five years are shaped by imported solutions retrofitted to Indian conditions, or by Indian science built for Indian scale from the outset.

This is the problem the Anusandhan National Research Foundation (ANRF) has chosen to attack head-on through its newest initiative: the MAHA Leapfrog Demonstrators for Societal Innovation in India programme.

What Exactly Is a "Leapfrog Demonstrator"?

The name is deliberate. A leapfrog, in development economics, describes a jump that skips over an intermediate stage altogether — think of how mobile phones let much of the world skip landline infrastructure entirely. ANRF's programme takes this idea and applies it to research translation: instead of nudging a technology forward one incremental improvement at a time, the goal is to engineer a genuine jump from promising idea to validated, adoptable, at-scale solution within a single, tightly integrated project.

According to the programme, a Leapfrog Demonstrator must show progress on four fronts simultaneously, not just one:

- **Technical maturity - the solution has been tested beyond the sheltered conditions of a lab, out in the messy variability of the real world.**
- **Usability and adoption - the people who are supposed to use it (farmers, hospitals, city agencies, industries) actually can, and show signs that they will.**
- **Scalability - there is field evidence from multiple sites or a district-level rollout, not just one pilot village.**
- **Economic viability - the numbers work; the cost per unit of benefit is low enough that scaling it up doesn't require infinite subsidy.**

A project that nails one of these say, a technically brilliant prototype with no plan for who pays for it or how it reaches a hundred villages instead of one does not qualify, however elegant the underlying science. The programme is unambiguous that incremental research, however solid, is not what it is designed to fund. It exists specifically for the harder, messier, more integrated work of proving that a solution can go the distance.

Two Ways In: Challenges and Open Tracks

Recognising that some of India's problems are already well enough understood to be posed as direct questions, while others need someone with a sharper diagnosis to define them first, the programme runs on two parallel tracks.

The Challenges Track is for problems ANRF itself has already framed. Periodically, the foundation will publish a defined national problem statement — a clear articulation of what is broken and what "fixed" would look like at national or regional scale and invite teams to propose a leapfrog response to it. Applicants under this track do not need to convince anyone that the problem matters; they need to convince the evaluators that their proposed solution represents a genuine transformation rather than a marginal tweak, and that they can prove it.

The Open Track, by contrast, hands the diagnostic work to the applicants themselves. Within a set of broad strategic areas, teams must make their own case: what is the problem, why has it resisted solution so far, and why is 2026 the moment it finally becomes solvable? This track rewards teams with a sharper, more original read of a national problem than the ones already on ANRF's radar — but it also demands a correspondingly more rigorous justification, since there is no pre-vetted problem statement to lean on.

Both tracks converge on the same underlying discipline: applicants must lay out an "AS-IS versus TO-BE" picture — where things stand today, and where they would stand if the demonstrator succeeds — pitched not at the level of one lab or one village, but at a scale that would actually matter for the country.

Where the Programme Wants to Make a Difference

The strategic areas the programme has flagged for attention read like a checklist of the unglamorous but urgent problems standing between India and its 2047 goals: resilient and sustainable agriculture, radical improvements in energy efficiency, safer and smarter transportation, air and water pollution, converting waste into economic value, more resilient infrastructure, preserving and monetising biodiversity, skilling and employment, community health, sports science and physical literacy, and expanding financial and digital inclusion.

None of these are new problems. What is new is the insistence that any funded project treat translation to real-world scale as a first-class design requirement from day one — not an afterthought added once the "real" research is done.

The Architecture Behind the Ambition: Hub and Spoke

A demonstrator of this kind rarely comes from a single institution working alone. ANRF has built the programme around a "hub-and-spoke" consortium model: a Lead Institution acts as the hub, anchoring coordination and validation of the whole demonstrator, while partner institutions serve as spokes, contributing the domain expertise, field access, or deployment capability the hub itself may lack.

Crucially, the model insists that industry and start-up partners sit inside this consortium from the start — not as an afterthought once the science is "ready for market," but as co-designers of the translation pathway itself. Purely academic teams without an industry, start-up, or translational partner are explicitly told they will not be prioritised. Government departments and civil society organisations, where relevant, are welcomed too, particularly for challenges with a strong public-service or equity dimension.

This is a meaningful departure from how a great deal of Indian research funding has traditionally worked, where a single principal investigator and their laboratory could reasonably expect to see a project through from proposal to completion in relative isolation. The Leapfrog Demonstrators programme instead treats the ecosystem — not the individual lab — as the unit that must be funded and evaluated.

The Scale of Support — and What It Signals

The numbers attached to the programme are themselves a statement of intent. Projects can be funded at two tiers: "medium" projects with a total budget of ₹10 to ₹25 crore, where ANRF's own contribution can reach up to ₹12.5 crore, and "large" projects with a total budget of ₹25 crore and upward — potentially well beyond ₹100 crore — where ANRF's contribution can go up to ₹50 crore. In both cases, the foundation requires at least half of the total project cost to be matched in cash from non-ANRF sources: industry, philanthropy, other government bodies, or institutional resources. Projects can run for as long as five years.

This is not modest seed funding for an interesting idea. It is capital sized for the kind of multi-site, multi-year, multi-partner effort that a genuine leapfrog — as opposed to an improvement — actually requires. The mandatory cash cost-sharing is also a filter in itself: a project that cannot attract a serious non-government co-funder is, implicitly, a project that has not yet convinced anyone outside the research community that it is worth betting on.

Who Can Lead One of These Projects

The eligibility rules reflect the same seriousness of intent. A Lead Principal Investigator must hold a regular (not contractual or visiting) position at an eligible academic institution, national research laboratory, or a mission-aligned not-for-profit research body, and must hold a doctoral degree in a relevant discipline. Early-career fellows under schemes such as INSPIRE, Ramanujan, or Ramalingaswami can be part of the team, but only as co-investigators, not as the lead. Researchers approaching retirement can still lead a project, provided a co-investigator with adequate remaining years of service is named alongside them, to see the multi-year project through.

Spoke institutions can include academic and research bodies as well as recognised non-profits and NGOs, provided they carry the relevant government recognition needed to receive grant funding directly. Industry and start-up partners, meanwhile, participate as co-investigators or honorary investigators rather than as direct grant recipients — they are compensated instead through contractual arrangements for specific services or deliverables, a structure meant to keep their incentives aligned with the project's translational goals without complicating the funding mechanics.

Why This, and Why Now

A recurring question the programme asks of every applicant is deceptively simple: why now? What has changed — in technology, in available data, in regulation, or in cost structures — that makes a leapfrog possible today that was not possible even a few years ago? This is not a rhetorical flourish. Proposals that answer it vaguely are explicitly marked down. The question forces applicants to demonstrate that they are not simply proposing overdue work, but capitalising on a genuine window of opportunity — the kind of window that, in a fast-moving research landscape, can close again if nobody moves through it in time.

There is also a clear-eyed insistence on what happens after a project ends. Prototypes and artifacts developed under the programme are expected to be widely shared rather than shelved, and datasets and models are meant to remain accessible and maintained well beyond the funding period — treated as public assets built with public money, not as private trophies of a completed grant.

A Small Piece of a Much Larger Puzzle

The Leapfrog Demonstrators programme does not stand alone. It has been designed to complement ANRF's other MAHA Mission Mode initiatives, and proposals that overlap more naturally with an existing mission are explicitly liable to be redirected there instead. In that sense, this programme occupies a specific niche in India's research funding landscape: not the earliest, most exploratory stage of an idea's life, and not the fully commercialised, market-ready stage either, but the demanding middle passage where a solution must prove — in the field, at scale, and on a budget that adds up — that it deserves to exist beyond the laboratory that first built it.

Whether this particular mechanism succeeds in doing what so many well-intentioned translation programmes before it have struggled to do will depend on execution: on whether the consortia it funds are genuinely integrated rather than assembled on paper, and on whether "why now" and "AS-IS versus TO-BE" remain rigorous evaluation questions rather than boxes to be checked.

But the underlying instinct is hard to argue with. A country aiming to arrive at its hundredth year of independence as a developed nation cannot afford to keep discovering good ideas and then losing them in the valley between the lab and the last mile. If the Leapfrog Demonstrators programme does even part of what it sets out to do, it will have helped close one of the quieter but more consequential gaps standing between India's research strength today and the India it hopes to be in 2047.

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PRITHVI SCHEME

Strengthening India's Earth System Science for Resilience and Growth

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The PRITHvi VIgyan (PRITHVI) Scheme is a comprehensive and integrated umbrella programme of the Ministry of Earth Sciences (MoES), aimed at advancing the country's capabilities in Earth system science. Approved with a financial outlay of Rs. 4797 cr for the period 2021–2026, the scheme consolidates multiple ongoing initiatives into a single, unified framework to promote efficiency, coordination, and scientific excellence. The scheme is designed to adopt a holistic approach to address all major components of the Earth system, including the atmosphere, oceans, geosphere, cryosphere, and biosphere.

The scheme has significantly enhanced India's capabilities in disaster early warning, climate and ocean services, seismic monitoring, and polar research. It has contributed directly to national priorities such as climate resilience, Blue Economy development, and the vision of Viksit Bharat@2047, while also supporting global commitments like Sustainable Development Goals (SDGs) 13 (Climate Action) and 14 (Life Below Water).

Ministry of Earth Sciences (MoES) is mandated to provide services for weather, climate, ocean and coastal state, hydrology, seismology, and natural hazards; to explore and harness marine living and non-living resources in a sustainable manner for the country and to explore the three poles of the Earth (Arctic, Antarctic and Himalayas). Earlier, different domains of Earth sciences—such as meteorology, oceanography, seismology, and polar research—were managed through separate schemes and institutions. While these initiatives achieved significant progress in their respective areas, the lack of integration often limited their overall impact. Earth systems are deeply interconnected, with changes in one component often influencing many others. Recognizing this, the PRITHVI scheme has been designed to unite diverse scientific disciplines under a single framework, enabling a holistic, systems-based approach. It merged five earlier schemes — ACROSS (Atmosphere and Climate Research – Modelling Observing Systems and Services), O-SMART (Ocean

Services, Modelling, Application, Resources, and Technology), PACER (Polar Science and Cryosphere Research), SAGE (Seismology and Geosciences), and REACHOUT (Research, Education, Training, and Outreach). This integration not only improves scientific understanding but also ensures that research outputs are effectively translated into actionable services for society.

The PRITHVI scheme is fully funded by the Government of India and implemented through MoES and its network of specialized institutions. These include the India Meteorological Department (IMD), National Centre for Polar and Ocean Research (NCPOR) Goa, National Institute of Ocean Technology (NIOT) Chennai, Indian National Centre for Ocean Information Services (INCOIS) Hyderabad, Centre for Marine Living Resources and Ecology (CMLRE) Kochi, National Centre for Coastal Research (NCCR) Chennai, National Centre for Earth Science Studies (NCESS) Thiruvananthapuram, National Centre for Seismology (NCS) New Delhi, National Centre for Medium Range Weather Forecasting (NCMRWF), Noida, Indian Institute of Tropical Meteorology (IITM) Pune and Borehole Geophysical Research Lab (BGRL) Karad. These institutions work in close coordination to ensure the effective implementation of the scheme's objectives. The scheme also involves collaborations with academic institutions and international organizations to strengthen research and innovation.

Objectives of the Scheme

The PRITHVI scheme is guided by a comprehensive set of objectives that reflect both scientific advancement and societal relevance. It seeks to strengthen long-term observational systems for monitoring the Earth's atmosphere, oceans, cryosphere, and solid earth. This includes the establishment and maintenance of advanced monitoring networks for the atmosphere, oceans, and geophysical processes, enabling the continuous recording of environmental parameters. It also aims to promote research and development in Earth sciences, supported by modern infrastructure and advanced technologies.

A key objective is the development of predictive models for weather, ocean conditions, and climate hazards, which are essential for disaster preparedness and risk reduction. In addition, PRITHVI aims to support sustainable development by providing critical data and advisories to sectors such as agriculture, fisheries, water resources, and urban planning. The scheme also focuses on monitoring seismic activity and assessing earthquake hazards, particularly in vulnerable regions.

Additionally, it emphasizes the exploration of polar regions and deep-sea environments for scientific knowledge and resource potential.

Another important goal is the development of technologies for sustainable utilization of ocean resources, including renewable energy and desalination. The scheme also prioritizes translating scientific knowledge into practical services for society, such as advisories for fishermen and early warning systems for disasters. Finally, it aims to build skilled human resources in Earth sciences through training, research support, and capacity-building initiatives.

Components of the Scheme

The PRITHVI scheme comprises five major components, each addressing a specific domain of Earth sciences while contributing to the overall integrated framework. The first component, ACROSS (Atmosphere and Climate Research – Modelling Observing Systems and Services), focuses on atmospheric science and climate research. It involves the development of advanced weather forecasting systems, climate models, and observation networks, which play a critical role in providing accurate weather predictions and early warnings for extreme events. The second component, O-SMART (Ocean Services, Modelling, Application, Resources, and Technology), deals with ocean-related activities, including the observation and monitoring of ocean parameters, resource exploitation, development of marine technologies, and provision of ocean advisory services. It integrates various oceanographic activities into a single framework aligned with India's Blue Economy vision. This component is particularly important for supporting coastal communities, fisheries, and the blue economy. The third component, PACER (Polar Science and Cryosphere Research), focuses on research in polar regions and the study of glaciers and ice systems. It includes scientific expeditions to Antarctica and the Arctic, as well as studies on the Himalayan cryosphere, which are essential for understanding global climate change and its regional impacts. The fourth component, SAGE (Seismology and Geosciences), addresses geophysical processes, including earthquake monitoring, seismic hazard assessment, and research on the Earth's interior. This component plays a vital role in disaster risk reduction and infrastructure planning. The fifth component, REACHOUT (Research, Education, Training, and Outreach), emphasizes capacity building, academic collaboration, and public engagement, ensuring that the benefits of Earth science research are widely disseminated and that a skilled workforce is developed for the future.

Significance of the Scheme

The PRITHVI scheme holds immense significance for India as it strengthens the country's ability to address environmental and climatic challenges in a comprehensive manner. One of its most important contributions is in the area of disaster risk reduction. India is highly vulnerable to natural disasters such as cyclones, floods, droughts, heatwaves, and earthquakes, and the scheme enhances early warning systems and preparedness measures, thereby reducing loss of life and property. The scheme also plays a crucial role in climate change research, providing valuable insights into climate variability, long-term trends, and potential impacts. This information is essential for developing effective mitigation and adaptation strategies and for fulfilling India's commitments under international agreements such as the Paris Agreement. Furthermore, PRITHVI supports key sectors of the economy by providing reliable data and advisories. In agriculture, weather forecasts help farmers plan sowing, irrigation, and harvesting activities, while in fisheries, ocean advisories guide fishermen to potential fishing zones and ensure their safety. The scheme also contributes to water resource management, urban planning, and infrastructure development by providing critical environmental data. Additionally, through its focus on ocean sciences, PRITHVI promotes the sustainable utilization of marine resources and supports the growth of the blue economy, which is an important driver of economic development.

Achievements of the Scheme

The PRITHVI scheme has yielded significant achievements and outcomes in the field of Earth sciences. The ACROSS sub-scheme has played a crucial role in strengthening India's weather and climate capabilities. One of its major achievements is the significant improvement in weather forecasting accuracy, with better prediction of extreme events such as cyclones, heatwaves, heavy rainfall, and thunderstorms. The sub-scheme has also contributed to the development of advanced early warning systems, including lightning alerts and nowcasting services that provide short-term forecasts for hundreds of locations across the country. In addition, the expansion of observational infrastructure, such as Doppler Weather Radars, high wind speed recorders, and improved atmospheric monitoring systems, has strengthened real-time data collection and analysis. The establishment of high-performance computing systems has further enhanced the ability to process large datasets and run complex weather and climate models. Another key achievement of the ACROSS sub-scheme is the development of advanced forecasting models, including global and regional numerical weather prediction models and ensemble systems. It has also supported the development of India's Earth System Model, improving long-term climate projections and contributing to global climate research. The scheme has significantly improved monsoon forecasting, which is critical for India's agriculture and water resources. ACROSS sub-scheme has enabled the dissemination of agrometeorological advisories to millions of farmers through various communication channels. It has also supported sectors such as aviation, fisheries, water resource management, and disaster management by providing tailored weather and ocean information services.

The OSMART sub-scheme has strengthened India's ocean-related research, services, and resource management. One of its major achievements is the improvement in ocean forecasting and advisory services, including accurate predictions of waves, tides, storm surges, and ocean currents.

These services are widely used by coastal communities, fishermen, and maritime agencies, enhancing safety and operational efficiency. A key contribution of the scheme is the development and dissemination of Potential Fishing Zone (PFZ) advisories, which help fishermen locate fish-rich areas, thereby increasing their catch while reducing fuel consumption and time at sea.

The scheme has also strengthened early warning systems for ocean-related hazards such as tsunamis, cyclones, and coastal inundation, helping minimize risks to life and property. OSMART has expanded ocean observation systems through the deployment of buoys, Argo floats, tide gauges, and other platforms that provide real-time data on ocean parameters. This has improved the understanding of ocean dynamics and supported better modelling and forecasting. The scheme has also enabled advancements in ocean modelling, including high-resolution ocean state forecasts and coupled ocean-atmosphere models. Another important achievement is progress in the exploration and sustainable utilization of marine resources. The scheme has supported deep-sea mining research, particularly for polymetallic nodules, as well as studies on marine biodiversity and ecosystems. It has also promoted the development of ocean technologies, including underwater vehicles, sensors, and desalination technologies.

The PACER sub-scheme has advanced India's capabilities in polar and cryospheric science. One of its key achievements is the strengthening of India's scientific presence in the Arctic, Antarctic, and the Himalayan cryosphere through sustained research expeditions and the establishment of modern research infrastructure. This has enabled continuous monitoring and data collection in some of the most climate-sensitive regions of the world. This data has been used to improve climate models and weather prediction systems. It has also helped in reconstructing past climate conditions using ice core studies, thereby providing insights into long-term climate variability. Research under PACER has improved knowledge about the melting of Himalayan glaciers and its implications for river systems, water security, and sea-level rise. The sub-scheme has also supported studies on polar biology, biodiversity, and ecosystem responses to changing climatic conditions. The enactment of the Indian Antarctic Act (2022) and the hosting of international treaty meetings highlight India's growing leadership in polar governance.

The SAGE sub-scheme has strengthened India's capabilities in earthquake monitoring and seismological research. One of its major achievements is the expansion and modernization of the national seismological network from 115 to 169 observatories, enabling real-time detection and analysis of earthquakes with improved accuracy. This has enhanced the ability to quickly assess earthquake parameters such as magnitude, depth, and epicentre. The sub-scheme has also contributed to the development of seismic hazard maps and microzonation studies for major cities, which are crucial for urban planning and disaster risk reduction. Scientific advancements include seismic microzonation of cities, deep drilling studies in the Koyna region, and improved understanding of India's lithospheric evolution and coastal dynamics. Research under SAGE has improved understanding of tectonic processes and earthquake generation mechanisms, particularly in seismically active regions.

The REACHOUT sub-scheme has focused on capacity building and research support. It has played an important role in promoting awareness and understanding of Earth system sciences among students, researchers, and the general public The scheme has also


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strengthened academic collaboration by supporting research projects, fellowships, and partnerships between institutions in India and abroad. It has funded around 150 research projects and conducted over 200 training programmes, strengthening India's scientific workforce and fostering international collaboration. Programmes such as ITCOcean, DESK, and BIMSTEC Centre for Weather and Climate provided specialized training and capacity building for professionals and students.

The Prithvi Scheme has strengthened India's role in global scientific collaborations by contributing to international research programs related to major components of the Earth system, including the atmosphere, oceans, geosphere, cryosphere, and biosphere. It has facilitated partnerships with other countries and institutions, enhancing data sharing and joint research initiatives. In addition, it has facilitated capacity building, technological advancements, and international collaboration. It has contributed to the growth of the blue economy by supporting sectors such as fisheries, shipping, offshore industries, and coastal zone management. It has also enhanced India's role in global ocean observation and research initiatives.

Challenges

Despite its comprehensive design and ambitious objectives, the PRITHVI scheme faces several scientific, logistical, infrastructural, administrative, and financial challenges, many of which were further aggravated by the COVID-19 pandemic, affecting timelines, operational continuity, and scientific outputs. Earth system science research inherently involves operations in remote and hostile regions such as the Polar areas, Southern Ocean, Himalayan glaciers, and islands, where accessibility constraints, limited weather windows, extreme environmental conditions, corrosion, biofouling, and vandalism significantly affect field activities and equipment performance. One of the major challenges is the need for advanced technological infrastructure, including research vessels, high-performance computing systems and sophisticated observation networks, which require significant investment and maintenance. The absence of a dedicated Polar Research Vessel restricted expansion of Arctic and Antarctic research activities. A persistent shortage of institutional core manpower, including scientific, administrative, legal, and technical personnel, severely constrained implementation capacity, continuity of expertise, training activities, and timely scientific outputs. Administrative delays and financial constraints, including land acquisition issues, dependence on international chartering costs, exchange rate fluctuations, and rising fuel prices, further affected project execution. Additionally, weak industry participation and limited availability of marine technology manufacturers and infrastructure providers emerged as significant barriers to advancing marine and offshore research capabilities under the scheme. Addressing these challenges requires continuous investment in technology, capacity building, and institutional strengthening.

Way Forward

To maximize the benefits of the PRITHVI scheme, several measures can be undertaken in the future. Technological innovation should be prioritized, particularly in the areas of artificial intelligence, machine learning, and advanced modelling techniques, which can significantly improve forecasting accuracy and data analysis. Strengthening international collaboration is vital, as it fosters the exchange of knowledge, expertise, and data, thereby enhancing the programme's overall effectiveness. Public-private partnerships can be explored to leverage additional resources and promote innovation. Capacity building should remain a key focus, with increased investment in education and training programmes to develop skilled professionals in Earth sciences. It is also important to enhance public awareness and outreach activities, ensuring that the benefits of the scheme reach all sections of society. Finally, integrating scientific findings more effectively into policy-making will strengthen evidence-based decisions, supporting both sustainable development and climate resilience.

The PRITHVI (Prithvi Vigyan) Scheme represents a transformative initiative in India's approach to Earth system science. By integrating multiple disciplines under a unified framework, it addresses the complex and interconnected challenges posed by climate change, natural disasters, and environmental degradation. The scheme not only advances scientific research but also delivers essential services that directly benefit society, contributing to disaster risk reduction, sustainable development, and economic growth. While there are challenges to be addressed, the potential benefits of the scheme are immense, and with continued support, innovation, and effective implementation, PRITHVI has played a pivotal role in strengthening India's resilience and establishing the country as a global leader in Earth sciences.

Transforming Seaweed into Opportunity
The CSIR Seaweed Mission

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Seaweeds are marine macroalgae—red, green and brown—that grow along coastlines and in shallow waters across the world's oceans. They are ubiquitous components of marine ecosystems and play a vital ecological role. Globally, seaweed resources are increasingly recognised as valuable commercial commodities, particularly in East and South-East Asia, where they support thriving industries and coastal livelihoods.

Beyond their economic potential, seaweeds provide important environmental services. They form the foundation of marine food webs, absorb excess nutrients from coastal waters, sequester carbon, and help mitigate ocean acidification. Global seaweed production currently exceeds 36 million metric tonnes annually and is valued at approximately USD 18 billion. Despite its extensive coastline and rich marine biodiversity, India's contribution to this rapidly growing sector remains modest.

Recognising this untapped opportunity, the Council of Scientific and Industrial Research (CSIR) launched the Seaweed Mission in 2019. The mission seeks to establish a sustainable seaweed-based economy by addressing critical challenges in cultivation, genetic improvement, industrial processing and high-value bioprospecting.

India is home to more than 800 species of seaweeds distributed across over 11,000 kilometres of coastline. The country also has nearly 171 million people living in 70 coastal districts, including around four million fishermen residing in over 3,200 fishing villages. The mission aims to improve the livelihoods of these coastal communities through innovative technologies in seaweed cultivation, processing and value addition.

Seaweed Farming

Mapping India's Seaweed Potential

Although India possesses abundant marine resources and scientific expertise, large-scale seaweed cultivation has been constrained by regulatory challenges and the ecological complexity of the coastline. To address these gaps, CSIR undertook a comprehensive nationwide pre-feasibility assessment of seaweed cultivation potential.

More than 250 coastal locations, including the Andaman & Nicobar Islands and Lakshadweep, were surveyed. Based on biological, geomorphological and socio-economic criteria, detailed studies were conducted at over 100 sites, leading to the identification of more than 75 locations suitable for commercial seaweed farming.

An equally important component of this exercise was community engagement. Local fishermen were trained in cultivation techniques, provided hands-on demonstrations and sensitised to the economic opportunities offered by seaweed farming. These efforts are laying the foundation for sustainable livelihood models across India's coastal regions.

Rural Population Empowered Through Seaweed Cultivation

Building the Foundation: Seaweed Seed Technology

One of the major constraints facing the seaweed industry is the limited availability of quality planting material. Commercially important species such as Kappaphycus and Gracilaria often have restricted natural distribution and inadequate seed supply, limiting large-scale cultivation.

To overcome this challenge, CSIR has developed artificial seedling production technologies based on micropropagation and clonal propagation methods. The country's first seaweed seed production facility has been established at the Marine Algal Station, a field laboratory of CSIR-CSMCRI at Mandapam, Tamil Nadu.

For the first time in India, this technology has been scaled up through a public-private partnership supported under a Corporate Social Responsibility (CSR) initiative. The innovation has also been recognised among the Top 100 Innovations of India in the India Innovation Yearbook 2023.

This technology forms the basis of Hub-I of India's Seaweed Park, where millions of high-quality planting materials will be produced annually. At the same time, researchers are developing improved non-GMO variants of commercially important seaweeds with enhanced growth rates and greater resilience to environmental stresses, thereby strengthening the genetic foundation of the industry.

Seaweed for Nutrition and Food Security

India's population is expected to approach 1.7 billion by 2050. Although significant progress has been made in reducing hunger and malnutrition, nutritional security remains a challenge.

With a large proportion of the population following vegetarian diets, seaweeds offer a sustainable source of essential nutrients, including high-quality proteins, omega-3 fatty acids, vitamins and minerals. Recognising this potential, CSIR has developed a range of value-added food products from seaweed biomass.

These include ready-to-eat snacks, bakery products, pasta, nutritional bars and beverages, demonstrating how marine resources can contribute to improved nutrition and food diversification.

Transforming Agriculture through Seaweed Biostimulants

Seaweed-derived biostimulants are emerging as an important tool for sustainable agriculture. However, scientific understanding of their active compounds, storage stability and interactions with soil microbiomes remains limited.

The CSIR Seaweed Mission is addressing these gaps through the development of stable, high-performance and Fertiliser Control Order (FCO)-

Seaweed Farming in coastal areas of India

compliant biostimulant formulations from indigenous seaweed resources. Indigenous seaweed resources are being harnessed to develop scalable, environmentally sustainable solutions for climate-resilient agriculture. Advanced metabolomic and multi-omics approaches are being employed to unravel the mechanisms underlying seaweed biostimulant efficacy.

Research is focused on identifying bioactive molecules, understanding plant–microbe interactions and optimising formulations for different crops and agro-climatic conditions. Studies have demonstrated the importance of preservation and storage conditions in maintaining product stability and efficacy.

The mission aims to deliver commercial biostimulant products benchmarked against global standards while also supporting hydroponic and biotechnology applications. Through multi-location field trials, these innovations are expected to promote wider adoption of sustainable agricultural practices and enhance crop productivity.

Towards a Circular Bioeconomy

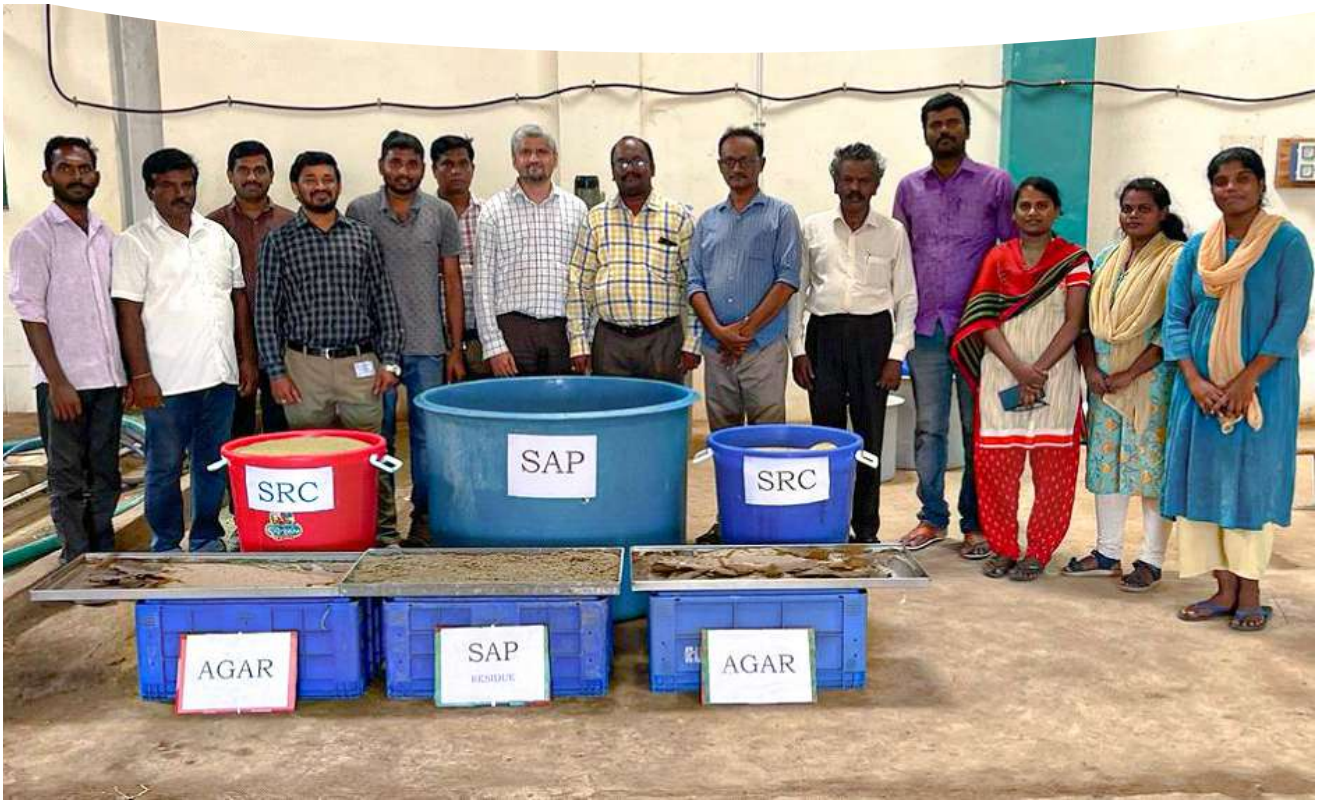
Building on its expertise, CSIR has developed a zero-waste process for producing liquid seaweed plant biostimulants from abundant brown seaweeds such as Sargassum wightii, Sargassum swartzii and Sargassum tenerrimum.

The process generates valuable co-products including phycocolloids, biodegradable films, cellulose and biochar, ensuring complete utilisation of biomass. The resulting liquid biostimulants act as effective plant growth promoters while reducing dependence on chemical fertilisers.

CSIR has also developed biodegradable films derived from seaweed-based phycocolloids as sustainable alternatives to conventional plastic packaging. Another innovation involves extracting nutrient-rich sap from Kappaphycus alvarezii, with the residual biomass subsequently processed for kappa carrageenan production.

Efforts are currently underway to scale up these technologies and develop standardised engineering packages that will enable industries and MSMEs to process commercial seaweed biomass into high-value products such as carrageenan, agar and alginate.

Researchers are also exploring seaweed extracts as environmentally friendly alternatives to chemical fungicides. Through laboratory and field studies, these extracts are being evaluated for their ability to enhance natural defence mechanisms in economically important crops.



From Seaweed to High-Value Bio-Based Products

Unlocking Marine Bioactives

Seaweeds are rich sources of bioactive compounds with applications in pharmaceuticals, nutraceuticals, cosmetics and healthcare products. Their diverse biological activities present significant opportunities for new product development.

Under the mission, scientists are investigating novel molecules from seaweeds and undertaking detailed studies on their biological efficacy, mechanisms of action and therapeutic potential.

Research on dolabellane-based compounds has resulted in the synthesis of around 25 analogues, some of which have shown promising anti-cancer activity. Bioactive compounds have also been isolated from species such as Stoechospermum marginatum, Gracilaria edulis and Dictyota dichotoma, opening new avenues for drug discovery and biomedical applications.

Ensuring Environmental Sustainability

Large-scale seaweed cultivation offers enormous opportunities for industrial growth and carbon sequestration. However, sustainable expansion requires careful evaluation of potential impacts on coral reefs, seagrass meadows and other marine ecosystems.

The mission is therefore undertaking detailed environmental assessments, including studies on carbon dynamics, species-specific physiological responses and ecological interactions. These efforts will support the development of science-based guidelines for environmentally responsible seaweed farming.

Strengthening Innovation and Intellectual Property

The Seaweed Mission is supported by a dedicated intellectual property strategy that provides real-time IP intelligence to researchers. This facilitates patent filing, technology protection and commercialisation, while strengthening the quality and strategic positioning of CSIR's innovations.

Towards India's Blue Economy

The CSIR Seaweed Mission is successfully transforming seaweed from a largely underutilised natural resource into a structured industrial sector. By integrating science, technology, entrepreneurship and community participation, it is laying the foundation for India's Blue Economy and maritime self-reliance.

CSIR has also played a key role in shaping national policy. Its scientific inputs contributed significantly to the NITI Aayog report "Strategy for the Development of Seaweed Value Chain" (June 2024), which provides a comprehensive roadmap for sustainable seaweed cultivation, processing and commercialisation in India.

Through livelihood generation, value addition, industrial innovation and environmental sustainability, the mission is creating new opportunities for coastal communities while strengthening India's self-reliance in seaweed-derived products and technologies.

From ocean to opportunity, the CSIR Seaweed Mission demonstrates how science-led innovation can unlock the immense potential of marine resources and contribute meaningfully to the vision of Viksit Bharat.

ADITYA-L1 MISSION

AI-Generated image

Indian Space Research Organisation (ISRO)

Aditya-L1, India's first dedicated space mission to study the Sun, was successfully launched on September 2, 2023 by ISRO's Polar Satellite Launch Vehicle (PSLV C-57). After its launch, the spacecraft underwent a series of orbital maneuvers and was successfully inserted into a halo orbit around the first Lagrangian point (L1) in the Sun-Earth system on January 6, 2024. This L1 point, located approximately 1.5 million kilometers from Earth, offers the unique advantage of continuous, uninterrupted observation of the Sun, free from eclipses or occultation.

Lagrange points are regions in space where the gravitational forces of two large bodies, such as the Sun and Earth, balance with the centripetal force acting on a smaller object. In the Sun-Earth system, these points allow a spacecraft to stay in a stable or quasi-stable position relative to the two bodies. There are five Lagrange points in the Sun-Earth system:

L1, L2, and L3: These are collinear with the two large masses (Sun and Earth) and are inherently unstable, meaning small perturbations can cause a spacecraft to drift away.

L4 and L5: These points form equilateral triangles with the Sun and Earth and are stable, allowing an object to remain at these points with less risk of drifting away.

Aditya-L1's placement at L1 allows for continuous monitoring of solar activity and provides pristine measurements of solar particles and magnetic fields, free from the influence of Earth's magnetosphere. Aditya-L1 carries a suite of seven scientific payloads—four for

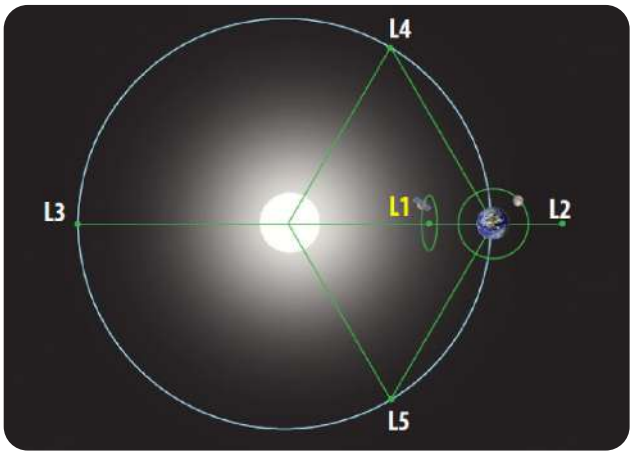


Illustration of Lagrange points of Earth-Sun system

remote sensing and three for in-situ measurements. The remote sensing in struments observe different layers of the Sun, including the photosphere, chromosphere, and corona, using various wavelengths of electromagnetic radiation. The in-situ payloads, including particle detectors and magnetometers, collect data on the local space environment around L1.

The mission's objectives include studying the dynamics of the solar corona, investigating the origins of coronal mass ejections (CMEs) and solar flares, as well as understanding the impact of these solar activities at the L1 point. The mission will also focus on the source regions of solar spectral irradiance variation, particularly in the near-ultraviolet (NUV) spectral band. Aditya-L1 is expected to make significant contributions to our understanding of solar processes.

Aditya-L1 Mission and Science Objectives

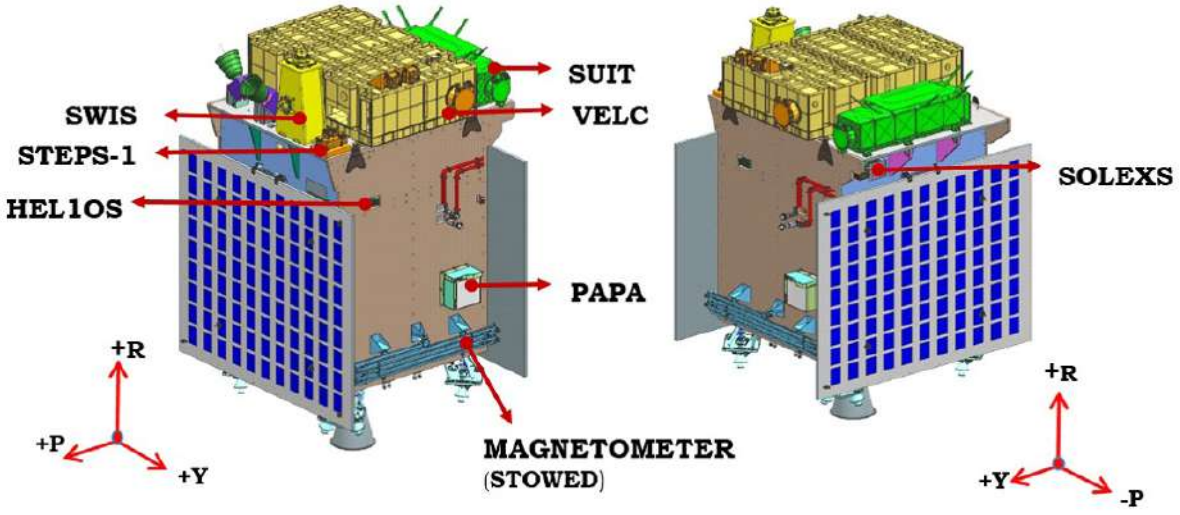
The Aditya-L1 spacecraft is configured to carry he following scientific payloads:

- **Visible Emission Line Coronagraph (VELC)**
- **Solar Ultra-violet Imaging Telescope (SUIT)**
- **Solar Low-energy X-ray Spectrometer (SOLEXS)**
- **High Energy L1 Orbiting X-ray Spectrometer (HEL1OS)**
- **Aditya Solar Wind Particle Experiment (ASPEX)**
- **Plasma Analyser Package for Aditya (PAPA)**
- **MAGnetometer (MAG)**

These payloads are selected to carry out the following major science objectives originally planned with Aditya-L1 mission:

- **Understand the acceleration phase of Coronal Mass Ejections (CMEs) in the lower corona and flares to provide handle on the drivers of space weather**
- **Understand the physics of chromospheric and coronal heating mechanisms and their atmospheric couplings through multi-wavelength studies**
- **Understand the association of solar spectral irradiance variability and its source regions**
- **Coronal plasma diagnostics over active as well as quiet regions including coronal magnetic fields in the active region corona.**
- **Spatio – temporal variability studies of particles and magnetic field at L1 point – an indicators for the terrestrial space weather.**
- **Kinematic studies of CMEs, Coronal Interactive Regions (CIRs), and Interplanetary CMEs, at L1 and its influence on the geo-effective events.**
- **Understand the source regions of geo-effective events using multi-payload observations.**

The payloads are located on Aditya-L1 spacecraft as shown in Figure below.



Locations of Aditya-L1 payloads on the spacecraft. R, P and Y indicates the Roll, Pitch and Yaw axis of the spacecraft

Aditya-L1 in clean room with location of some of the payloads

global utilization. Since then scientific data are released in public domain within 24-48 hours of data acquisition. At present, around 30 TB of Aditya-L1 data is available in public domain. The data are available at https://www.issdc.gov.in/aditya1.html.

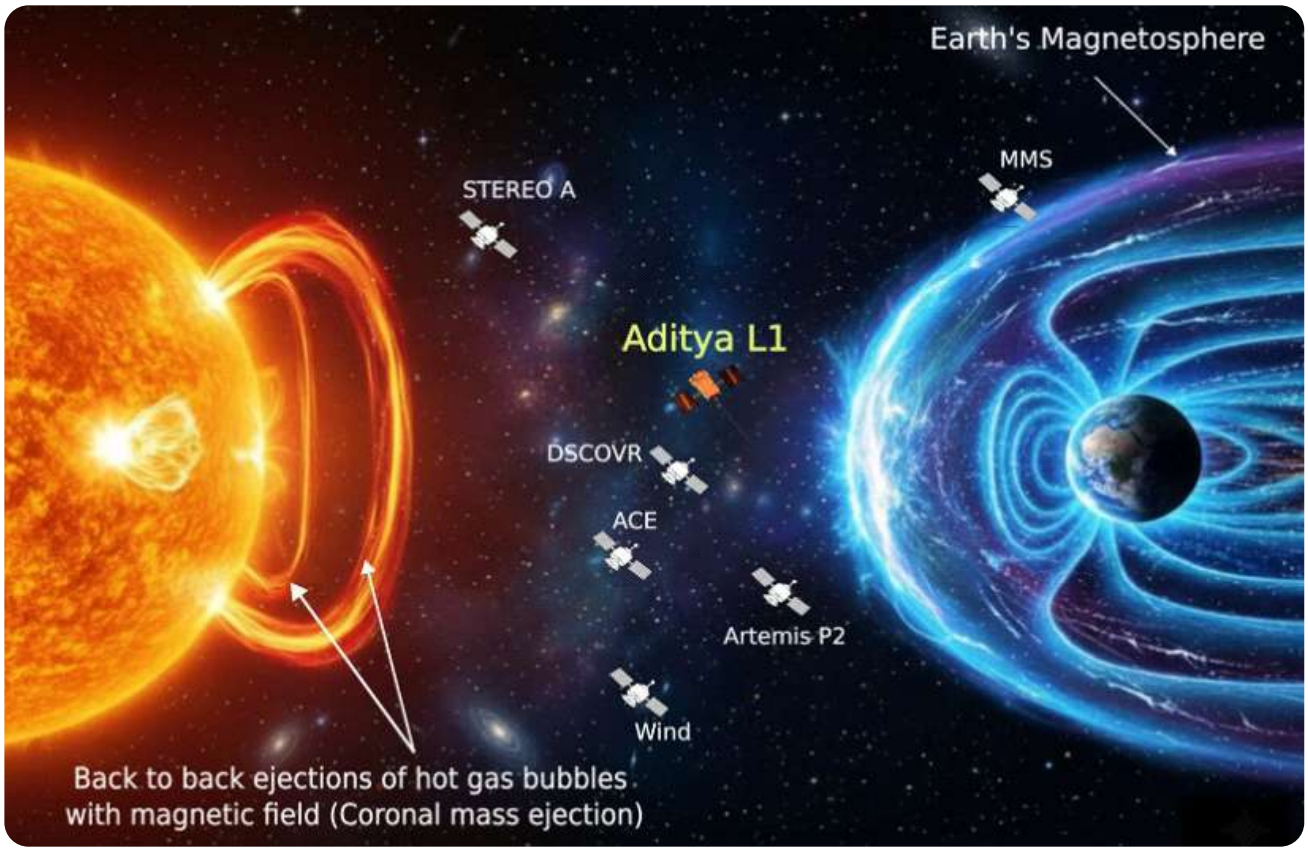
On 6 Jan 2026, ISRO opened Aditya-L1 for proposal submission for Aditya-L1 observation time by national solar science community through the release of Announcement of Opportunity (AO). Two AO cycles (A01 and A02) have been released so far.

Aditya-L1 Science Data Release

On the occasion (6 Jan 2025) of the first year anniversary of successful insertion of Aditya-L1 in the halo orbit around L1, ISRO conducted the National Meet on Aditya-L1 payload performance and released the scientific data of Aditya-L1 in public domain for

Key Science Outcome

The scientific outcomes from Aditya-L1 so far are significant and many scientific papers have been published in International peer reviewed journals. Aditya-L1 Topical collection has been completed (Solar Physics, 2025, 300). Since halo orbit insertion



Artistic illustration of the ejection of hot gas bubbles and magnetic field from the Sun, known as Coronal Mass Ejections. These two back-to-back CMEs collided in interplanetary space, and the embedded magnetic field lines snapped and rejoined, as captured by Aditya-L1 and six other spacecraft from NASA and NOAA, as shown in the above figure. The figure and spacecraft positions are not drawn to scale and are for illustrative purposes only

(6 Jan 2024) the number of papers published related to Aditya-L1 are around 50 numbers while the total publications related to Aditya-L1 are 79. Some of the key science results are highlighted below:

Solar storm study

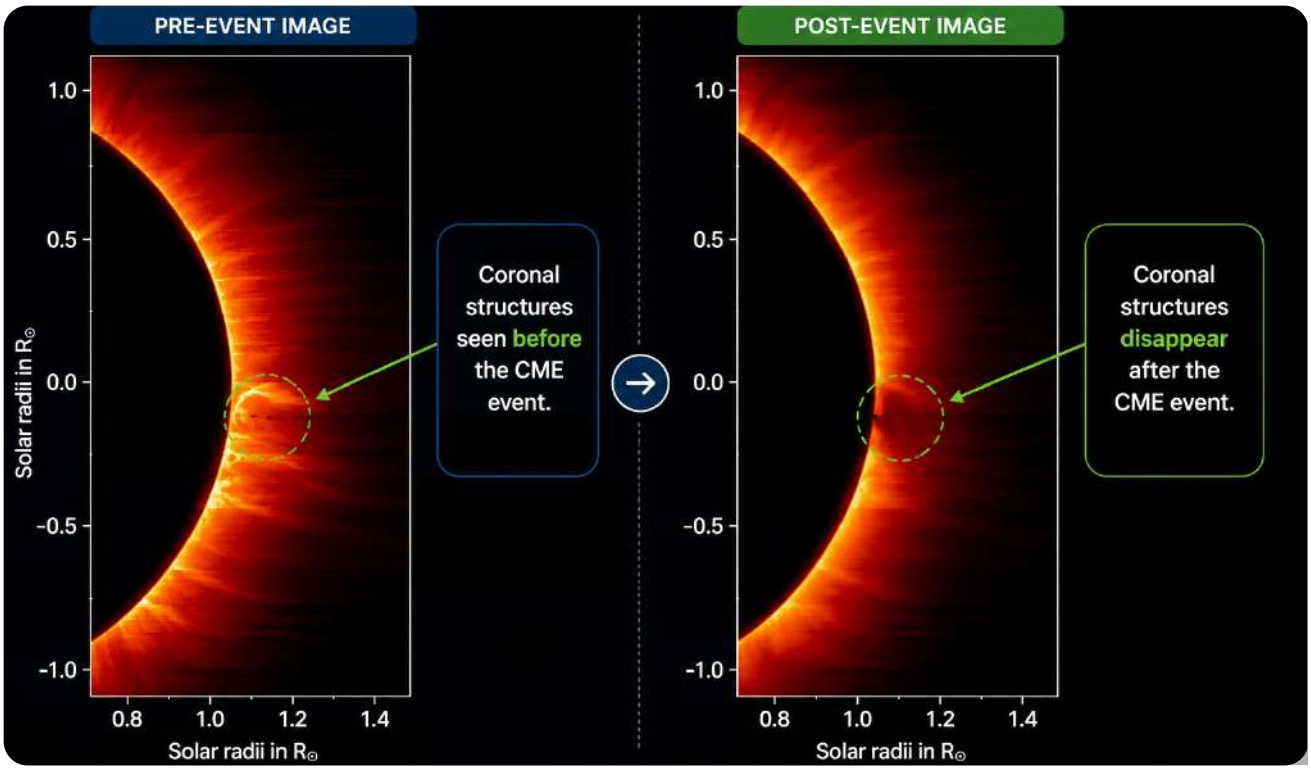
In May 2024, Earth experienced its strongest solar storm in over 20 years, now called "Gannon's storm." It was caused by huge solar eruptions called coronal mass ejections, or CMEs—massive clouds of hot gas and magnetic energy thrown from the Sun. When CMEs reach Earth, they can disturb the planet's magnetic shield and affect satellites, GPS, communications, and power grids.

A study published Indian scientists in Astrophysical Journal Letters suggests why this storm was so unusual. Researchers found that two CMEs collided in space, compressing their magnetic fields so strongly that the field lines broke and reconnected in new patterns. This process, called magnetic reconnection, suddenly reversed parts of the magnetic field. Satellite observations also showed particles gaining energy, supporting this finding.

India's Aditya-L1 solar observatory played a key role, working with six U.S. satellites: Wind, ACE, THEMIS-C, STEREO-A, MMS, and DSCOVR. Together, they observed the storm from multiple locations in space. Aditya-L1's magnetic field data helped scientists identify a huge reconnection region about 1.3 million kilometers wide. This was the first direct observation of such a large magnetic reconnection event inside a CME. The discovery improves our understanding of how solar storms change on their way to Earth and highlights India's growing role in space-weather research.

Similarly, using observations from Aditya-L1 mission, together with data from other international space missions, ISRO scientists and research students studied a major solar storm that struck Earth in October 2024. Their study, published in The Astrophysical Journal in December 2025, found that the storm was triggered by a large eruption of solar plasma from the Sun.

The most intense impact came from the storm's turbulent region, which Aditya-L1 helped identify. This region strongly squeezed Earth's magnetic field, pushing it unusually close to the planet and briefly exposing some geostationary satellites to harsh space conditions. Such effects are usually seen only during severe space-weather events.



Images of the west limb of the Sun (where the CME occurred) that were generated using VELC raster scan observations, before and after the CME. It is seen that the coronal structures in the pre-event image have disappeared in the post-event image. This happens in a CME due to ejection of coronal material from the Sun. In the image the horizontal and vertical axis are represented in Solar radius

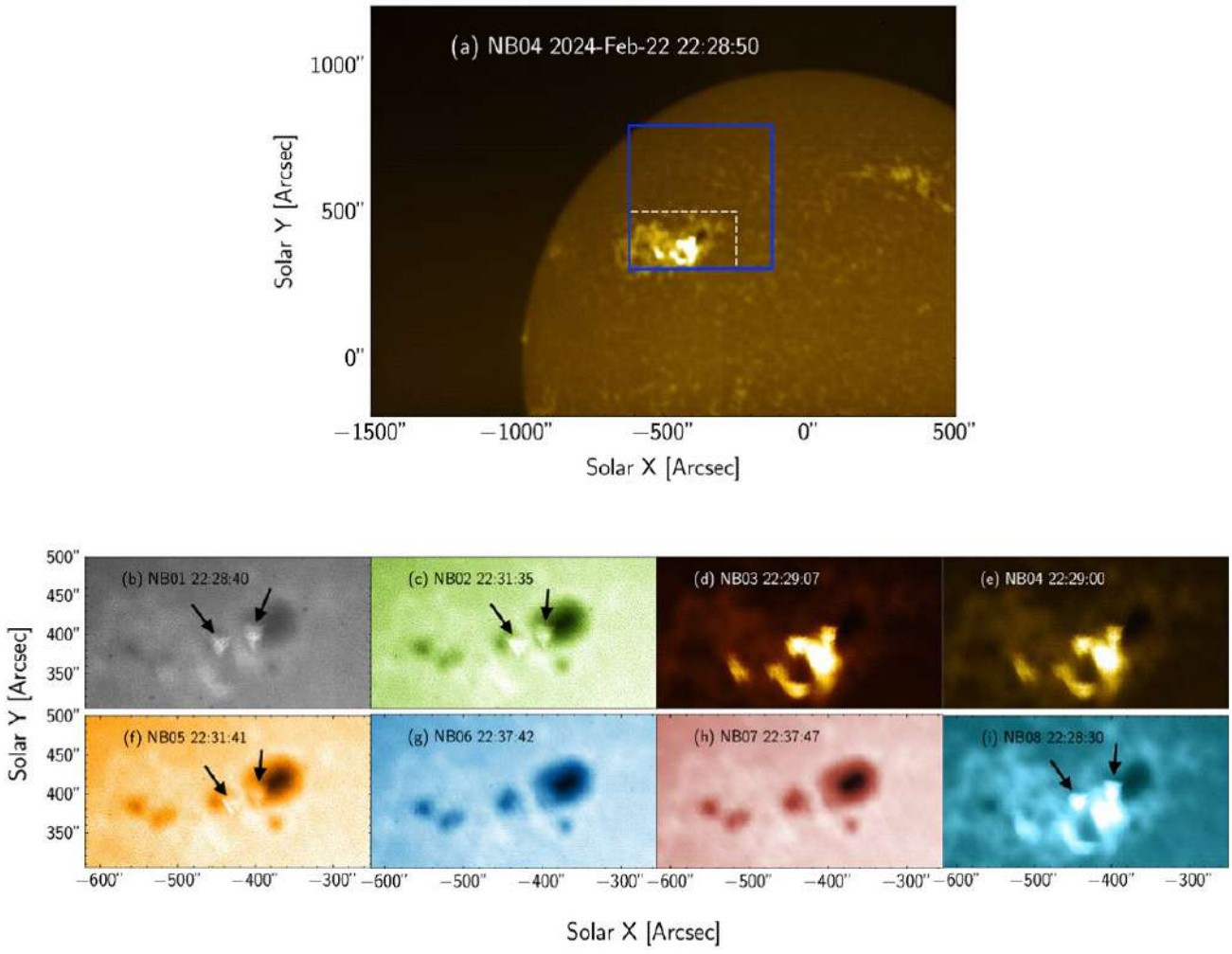
Observation of Coronal Mass Ejection:

Aditya-L1's VELC instrument observed a Coronal Mass Ejection (CME), revealing a 50% coronal dimming which lasted for about 6 hours and around 30% temperature increase with heightened turbulence. It is also detected a redshifted plasma outflow at 10 km/s after ejection of CME. These observations confirm the CME's material ejection and highlight the Sun's magnetic field's influence on the CME's trajectory which are crucial for space weather science to help in space weather forecasting.

Observations of strong solar flare

Aditya-L1 instruments have observed an X6.3-class solar flare, one of the most intense categories of solar eruptions. What makes this discovery unique is that SUIT detected brightening in the near ultraviolet wavelength range (200-400 nm) —a wavelength range never observed before in such detail. These observations confirm and ascertain that the energy from the flare spread through different layers of the Sun's atmosphere, providing new insights into the complex physics behind these massive solar explosions.

Observation of the flare as obtained from various SUIT filters. SUIT observed two bright kernels in various channels marked by arrows. The appearance of these bright kernels in NB02 and NB05 is highly interesting as these two filters observe the solar photosphere, which is lower than the chromospheric emissions. This implies that the effect of this flare affected the layers below the chromosphere.



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India's Clean Energy Transition
Accelerating the Path to Viksit Bharat 2047 and Net Zero 2070

Dr. Nisha Mendiratta

Head & Scientist G
Climate, Energy and Sustainable Technology (CEST) Division
Department of Science and Technology
Government of India

India's Clean Energy Transition at a Turning Point

The global energy landscape is undergoing a profound transformation, driven by climate change, energy security concerns, and rapid technological innovation. Clean energy has evolved from an environmental imperative to a strategic driver of economic growth, industrial competitiveness, and national resilience. Across the world, countries are accelerating investments in renewable energy, green hydrogen, energy storage, digital power systems, and low-carbon technologies to build sustainable and secure energy futures.

For India, this transition provides a unique opportunity to achieve Viksit Bharat 2047 while fulfilling its commitment to Net Zero by 2070. Balancing rising energy demand with rapid decarbonization, India has embraced an innovation-led approach by strengthening indigenous research, expanding domestic manufacturing, and fostering global partnerships. The country's early achievement of

> **India's clean energy transition is not merely an environmental imperative — it is a strategic opportunity to strengthen energy security, technological leadership, industrial competitiveness, and sustainable economic growth while advancing the vision of Viksit Bharat 2047.**

its Paris Agreement targets, along with the rapid growth of non-fossil energy capacity, reflects its commitment to building a clean, resilient, and self-reliant energy ecosystem.

This article explores India's clean energy transition through the lens of science, technology, and innovation, highlighting the pivotal role of the Department of Science and Technology's Climate, Energy and Sustainable Technology (CEST) Division in advancing research, demonstration, and commercialization of clean energy technologies, while strengthening India's leadership through global initiatives such as Mission Innovation.

The Global Clean Energy Landscape

The pace of the global energy transition has accelerated markedly driven by climate commitments. According to the International Energy Agency, global energy investment is on track to reach roughly USD 3.4 trillion, of which clean energy technologies account for an estimated USD 2.2 trillion nearly double the sum still flowing into oil, gas and coal. At COP28, nearly 200 countries agreed to triple global renewable capacity and double the rate of energy-efficiency improvement by 2030. Three trends define this moment: steep cost declines have made solar, wind and battery storage the cheapest source of new generation in most markets; energy security has become as significant driver of investment as decarbonisation, with governments treating domestic renewable capacity as a geopolitical hedge; and the frontier of the transition is advancing beyond electricity into harder-to-abate sectors — steel, cement, aviation and shipping where hydrogen and carbon capture are becoming indispensable. For India, this confirms that its own investment in indigenous capability across solar manufacturing, hydrogen and storage is well aligned with the direction of global capital.

India's Multi-Dimensional Energy Transition

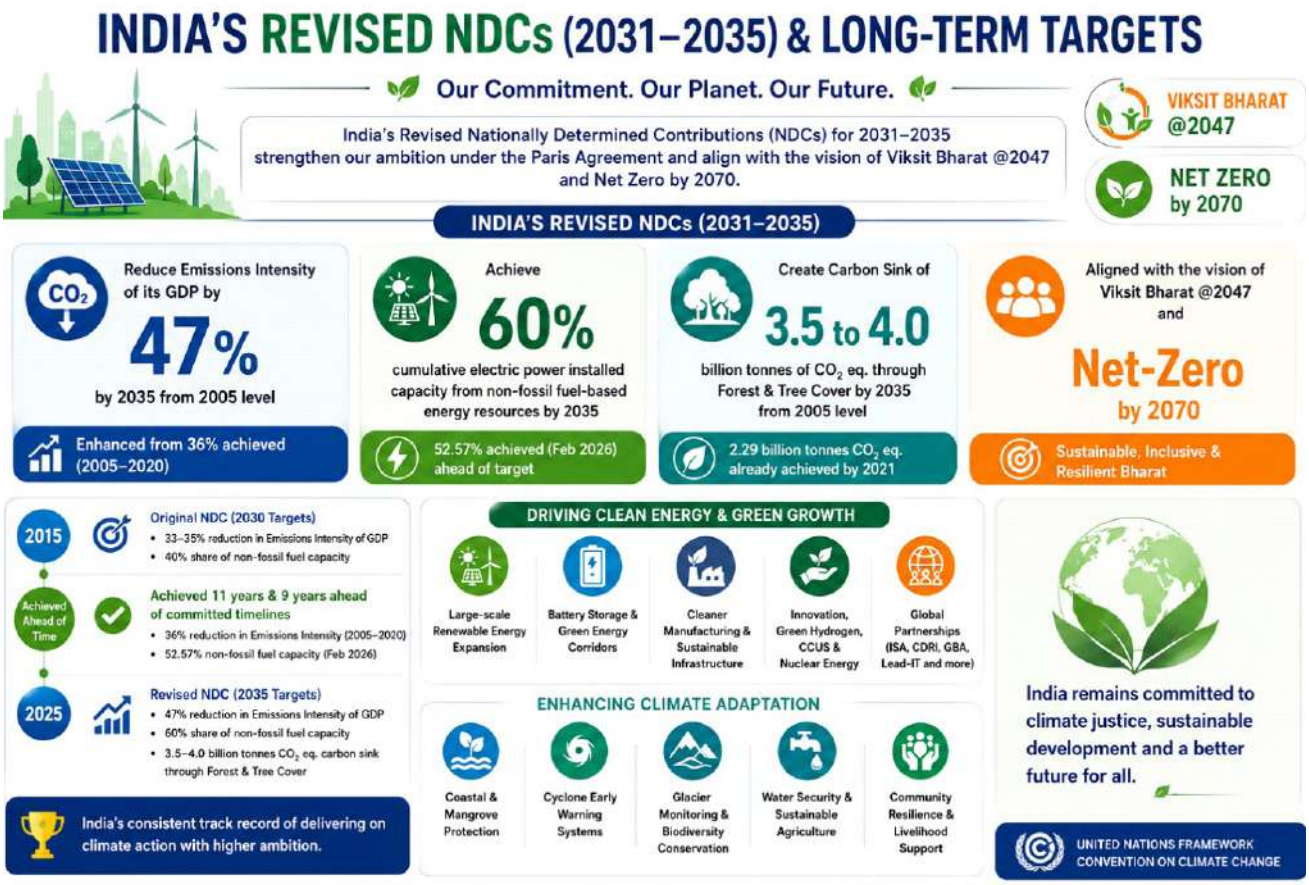
India's energy transition is best understood not as a single scheme but as a transformation unfolding simultaneously across generation, storage, mobility, industry and grid infrastructure. India is now the world's third-largest market for installed renewable capacity, behind only China and the United States, having added a record 55.29 GW of non-fossil capacity in FY 2025–26 nearly double the previous year's addition, taking cumulative non-fossil capacity to 283.46 GW. Solar power has crossed 150 GW, spanning utility-scale parks, rooftop systems and agricultural applications under PM-KUSUM, while wind capacity has crossed 56 GW, bringing the Prime Minister's COP26 target of 500 GW of non-fossil capacity by 2030 well within reach. Rooftop solar merits particular mention as a democratising force in this transition. The PM Surya Ghar: Muft Bijli Yojana, launched in 2024 with an outlay of approximately ₹75,021 crore, aims to install rooftop systems on one crore households, extending up to 300 free units a month while enabling families to sell surplus power back to the grid; cumulative rooftop capacity had crossed 30 GW by mid-2026. Domestic manufacturing has scaled in parallel, with India's solar module capacity rising from 2.3 GW in 2014 to over 170 GW today.

Green hydrogen represents the next frontier. The National Green Hydrogen Mission, approved in 2023 with an outlay of ₹19,744 crore, targets at least 5 million tonnes of annual production capacity by 2030, expected to catalyse over ₹8 lakh crore in investment and six lakh jobs, with three designated Green Hydrogen Hubs Deendayal, V.O. Chidambaranar and Paradip already hosting pilots across steel, mobility, shipping and fertiliser applications. Energy storage and mobility complete the picture: India is expanding battery manufacturing under Production-Linked Incentive schemes, exploring sodium-ion and solid-state chemistries to reduce import dependence, and advancing electric mobility through the EvolutionS of DST. Together, these strands illustrate that India's transition is a system-wide reconfiguration of how the nation generates, moves and consumes energy.

Integrated Policy Landscape

India's climate framework relates to the "Panchamrit" commitments which was announced by the Hon'ble Prime Minister at COP26. India's response is anchored in its broader development and climate vision through Nationally Determined Contributions (NDC). The NDC commitments and the long-term vision of Viksit Bharat emphasize sustainable, inclusive growth. Complementing this is India's climate-resilience agenda, coordinated through the National Action Plan on Climate Change (NAPCC) and DST-led missions that build the scientific knowledge base underpinning climate-resilient planning across sectors and states.

Most of the commitments have been achieved years ahead of schedule and now extended through the NDC for 2031–2035, which raises the emissions-intensity target to 47% and the non-fossil capacity target to 60% by 2035, alongside a carbon-sink target of 3.5–4.0 billion tonnes of CO_2 equivalent through forest cover, all explicitly anchored to Viksit Bharat @2047 and Net Zero 2070.



India's Revised Nationally Determined Contribution (2031–2035), approved by the Union Cabinet

Beneath this framework sits a dense architecture of missions, each addressing a distinct link in the value chain the National Green Hydrogen Mission, PM Surya Ghar, PM-KUSUM, PM E-Drive, the Smart Grid Mission and Green Energy Corridors, and the National Bioenergy Programme. These do not function as disconnected schemes but reinforce one another: a rooftop solar subsidy is matched by a manufacturing incentive ensuring the panel is made in India; a hydrogen production target is matched by a renewable capacity mandate ensuring the electrolyser runs on clean power.

Science, Technology and Innovation: The Backbone of the Transition

The Department of Science and Technology (DST), Government of India, serves as the nodal agency for promoting science, technology, and innovation across critical sectors of national importance. Within DST, the Climate, Energy and Sustainable Technology (CEST) Division has emerged as a key thematic division dedicated to addressing challenges associated with energy security, climate change, and sustainable development. The division plays a central role in advancing India's transition towards a low-carbon and resource-efficient economy, in alignment with national and global climate commitments.

The growing urgency of climate change, coupled with increasing energy demand and environmental constraints, has necessitated a shift from conventional energy systems to clean, sustainable, and resilient technological solutions. In this context, the CEST Division functions as a mission-driven platform, integrating scientific research, technological innovation, and policy support to enable transformative change in the energy and climate landscape of India.

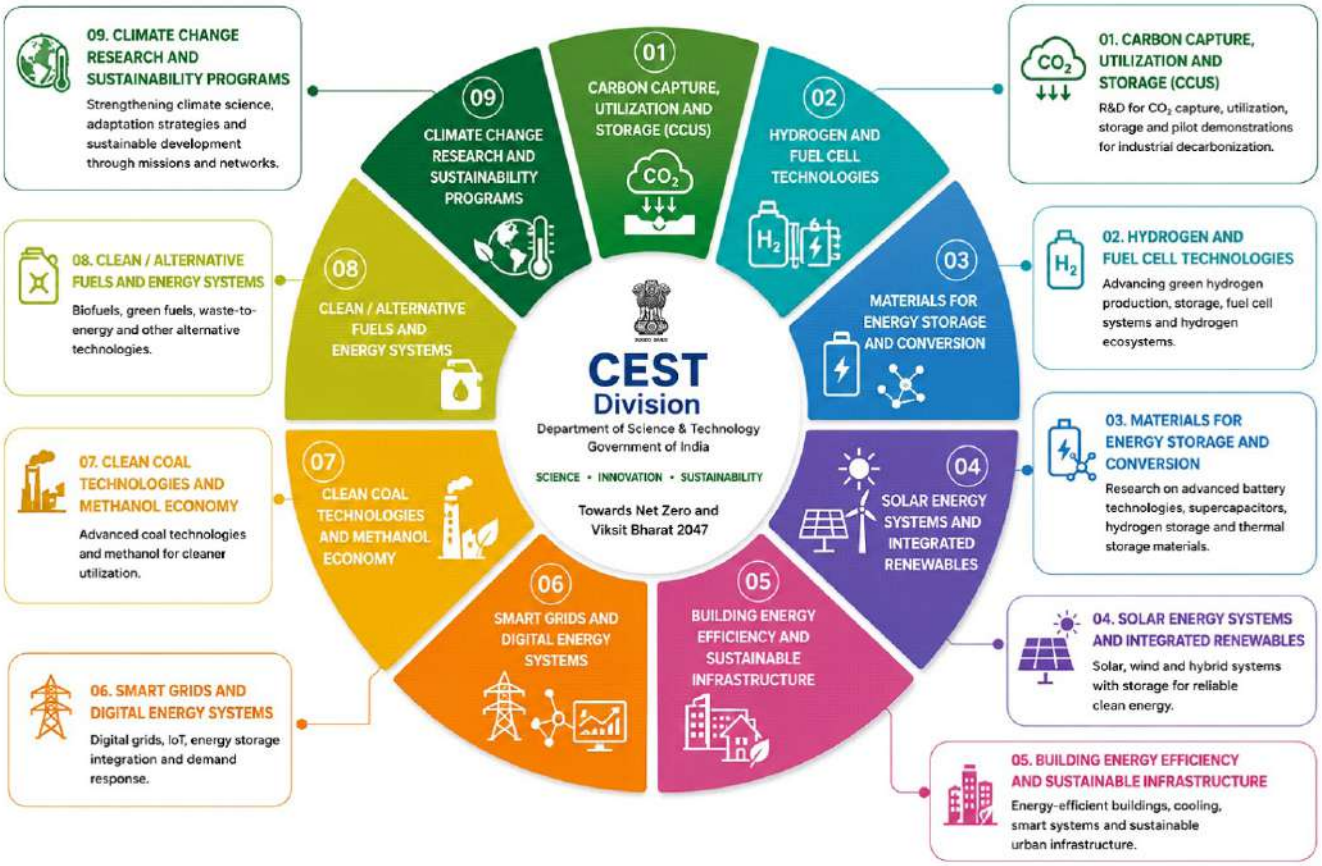
CEST : The Strategic Context & Initiatives

The Climate, Energy and Sustainable Technology (CEST) Division reflects India's commitment to sustainable development and climate action in line with the Paris Agreement and the National Action Plan on Climate Change (NAPCC). The Division has evolved from supporting fundamental energy research to promoting translational R&D, technology demonstration, and deployment across clean energy and climate technologies.

CEST focuses on renewable energy, climate science, carbon capture, hydrogen and fuel cells, industrial decarbonization, electric mobility, clean coal technologies, alternative fuels, building energy efficiency, and water technologies. Recognizing that India's clean energy transition requires a systems-level approach, the Division supports interdisciplinary research, innovation, and industry-academia collaboration.

Monitoring and Mitigation Technologies (M^3T) programme develops technologies for monitoring and reducing methane emissions across the energy, mining, waste, and wastewater sectors.

DST has strengthened the renewable energy innovation ecosystem through R&D in solar photovoltaics, wind energy, small hydropower, hybrid renewable systems, and energy storage. It supports next-



The thematic areas of DST's Climate, Energy and Sustainable Technology (CEST) Division

DST serves as the nodal agency for two national climate missions under NAPCC—the National Mission for Sustaining the Himalayan Ecosystem (NMSHE) and the National Mission on Strategic Knowledge for Climate Change (NMSKCC). These missions strengthen India's scientific capacity through climate modelling, vulnerability assessment, adaptation and mitigation research, Himalayan ecosystem conservation, capacity building, and international collaboration, while facilitating the translation of research into technologies, policies, and community-based solutions.

The Carbon Capture, Utilization and Storage (CCUS) programme supports research, pilot demonstrations, and deployment of technologies for CO_2 capture, utilization, and storage, with emphasis on hard-to-abate sectors such as steel, cement, power, and chemicals. Complementing this, the Methane

generation photovoltaic technologies, advanced wind systems, grid integration, and decentralized renewable energy solutions.

Hydrogen is a major focus area, with Hydrogen Storage Centres and four Hydrogen Valley Innovation Clusters established at Jodhpur, Bhubaneswar, Pune-Mumbai, and Kochi-Alappuzha to demonstrate integrated hydrogen production, storage, and end-use applications. The Materials for Energy Storage (MES) programme supports advanced battery technologies, including lithium-sulphur, sodium-ion, solid-state, metal-air, and flow batteries, along with materials for hydrogen and fuel cells.

Tangible outcomes include a rapidly charging e-cycle built on sodium-ion batteries and supercapacitors, a vanadium-based flow battery for grid-scale storage, and a family of nano-carbonflorate-

coated heating devices developed for smoke-free thermal applications relevant to clean cooking and rural energy access.

The Clean Coal Technologies Programme promotes efficient coal utilization through advanced ultra-supercritical (AUSC) technologies, coal gasification, and methanol production. The Clean Fuels and Alternative Energy programme supports biofuels, biomass conversion, waste-to-energy, synthetic fuels, and other low-carbon fuel technologies.

To accelerate electric mobility, the EvolutionS programme supports R&D in battery cells, power electronics, traction motors, and charging infrastructure. In collaboration with the Bureau of Indian Standards (BIS), DST contributed to the development of 25 national standards for EV charging infrastructure, strengthening interoperability and safety. DST also advances smart grids and building energy efficiency through international collaborations, supporting microgrids, energy storage, smart distribution systems, innovative building materials, and smart controls that improve energy efficiency in buildings.

The Water Technology Initiative (WTI) supports the complete research, development, demonstration, and deployment value chain for sustainable water technologies, promoting user-centric solutions that address regional needs through laboratory research, field demonstrations, and technology adaptation.

The Clean Coal Technologies Programme improves coal efficiency and environmental performance while promoting cleaner fuels via coal gasification and methanol technologies. The Advanced Ultra Super Critical (AUSC) Programme has established India's first High Temperature Spin Test Rig (HTSTR) and advanced high-temperature material testing facilities, including the FSCTR at NTPC Dadri, for validating indigenous 800 MW AUSC technologies. The Clean Fuels and Alternative Energy Programme supports the development of sustainable fuels including biofuels, waste-to-energy technologies, biomass conversion, synthetic fuels, and emerging low-carbon energy systems.

On the mobility side, electric vehicles are moving from niche to mainstream, supported by the newly created EvolutionS program which channels dedicated initiatives into battery cells, power electronics, traction motors, and charging infrastructure. It is envisaged to strengthen the country's electric mobility innovation ecosystem through a series of strategic R&D and standardization initiatives. DST, in collaboration with the Bureau of Indian Standards (BIS), contributed to the development of 25 national standards for EV charging infrastructure, which have been notified through the Gazette of India, establishing a robust foundation for interoperability, safety, and large-scale deployment of EV charging systems. This is a translational R&D

DST supported CO2 to methanol CCUS test beds

philosophy identify a gap, fund early-stage research through public-private partnership, build a pilot at meaningful scale, and only then hand the technology to industry.

Smart grids and building energy efficiency complete this innovation architecture. Since the SEGES programme's launch in 2014 in the aftermath of India's 2012 blackout, DST has anchored a succession of bilateral smart-grid collaborations with the UK, the US (the UI-ASSIST project on smart distribution systems with storage), and the European Union cumulatively deploying microgrids, energy storage, and smart distribution pilots across urban, rural, and island settings from Lakshadweep to Shillong to Ghoramara Island in West Bengal, where a 160 kW solar plant with 720 kWh of battery storage now powers a previously under-electrified community.

On the buildings side, four successive international R&D phases — with the US, UK, and through the DST-RMI Global Cooling Prize — have advanced innovative building materials (phase-change materials, low-carbon bricks, aerogels) and smart building controls, together delivering measured energy-demand reductions of 10–12% in participating buildings.

Mission Innovation: India's Global Leadership

Mission Innovation is the global platform through which India's domestic research connects to a wider community of innovators and investors. Launched at COP21 in 2015, it today brings together 22 countries

The RE-EMPOWERED field demonstration at Ghoramara Island, West Bengal

and the European Union around the shared goal of making clean energy affordable and accessible; its second phase from 2021-2030 sharpens this into seven mission areas spanning zero-emission shipping, clean hydrogen, green powered future, net-zero industries, integrated biorefineries, urban transition and carbon-dioxide removal. Since 2023, DST has served as India's national nodal point, hosting the MI-8/CEM-14 Ministerial in Goa in 2023 one of the year's largest global clean energy convenings, featuring a USD 10.6 billion investment announcement and showcasing India's major initiatives at subsequent gatherings in Bali (2024), Brazil (2024), Seoul (2025), Busan (2025) and Brussels (2026). India's own DST-Rocky Mountain Institute Global Cooling Prize, advancing residential cooling at a fraction of conventional climate impact, is now regarded internationally as a model for prize-based innovation.

Mission Innovation, launched at COP21 Paris (2015), now brings together 23 countries and the European Union around a shared goal: affordable, attractive and accessible clean energy for all.

The Way Forward

India's clean energy transition requires sustained research, accelerated technology translation, stronger public-private partnerships, and deeper scientific collaboration. Continued efforts through DST's CEST scientific programme Division, strengthened industry-academia linkages, expanded global engagement through platforms such as Mission Innovation and the International Solar Alliance, and a strong focus on manufacturing, skilling, and commercialization will be critical to transforming laboratory innovations into large-scale deployment. As India progresses towards Viksit Bharat 2047 and Net Zero 2070, the convergence of indigenous innovation, scientific excellence, and global partnerships will be central to building a resilient, energy-secured, and globally competitive clean energy ecosystem while contributing meaningfully to global climate action.

Mission Innovation Annual Gathering & Clean Energy Ministerial Senior Officials Meeting 2026 Brussels, Belgium

YUVIKA & NE-SPARKS

Indian Space Research Organisation (ISRO)

India's remarkable achievements in space exploration—ranging from cost-effective satellite launches to ambitious interplanetary missions—are largely driven by the vision and innovation of the Indian Space Research Organisation (ISRO). However, sustaining this legacy requires continuous investment not just in technology, but in human talent. Recognizing this need, ISRO launched an innovative initiative called the Young Scientist Programme, popularly known as YUVIKA (YUva VIgyani KAryakram) in Year 2019. Young Scientist Programme YUVIKA was conceived to impart basic knowledge on Space domain and ignite scientific curiosity among school students and inspire them to pursue careers in space science and technology. The programme envisages 2 weeks' class room training, practical demonstration of experiments, hands on Robotic kit, Model rocketry interactions with ISRO scientists and field visits.

The programme is applicable to Indian students studying in Class 9 across India, providing them with a unique opportunity to learn directly from some of the country's leading scientists.

The core philosophy behind YUVIKA is encapsulated in ISRO's approach: "catch them young." By identifying and nurturing talent at an early stage, the programme seeks to build a strong foundation for the next generation of scientists, engineers, and innovators. By exposing students to scientific methods and critical thinking and hands-on training, YUVIKA contributes to the development of a scientific temper—a key objective of India's new education policy, NEP-2020.

Objectives of the Programme

The YUVIKA programme has several well-defined objectives that align with India's long-term goals in science and technology:

1. **Early Exposure to Space Science: The programme introduces students to complex concepts such as satellite systems, rocket propulsion, and astrophysics in an accessible manner.**
2. **Promotion of STEM Education: One of the primary goals is to encourage students to pursue careers in Science, Technology, Engineering, and Mathematics (STEM).**

3. **Bridging Theory and Practice: YUVIKA emphasizes experiential learning by combining classroom lectures with hands-on activities and experiments.**
4. **Inclusion and Diversity: Special weightage is given to students from rural backgrounds to ensure equitable access to opportunities. It also brings students from different states in one programme thereby allowing them to understand and appreciate different cultures across India**
5. **National Capacity Building: The programme aims to create a pool of scientifically aware and motivated youth who can contribute to India's future technological advancements.**

Eligibility and Selection Process

YUVIKA is open to students studying in Class 9 in any recognized school across India at the time of application process. The selection process is based on multiple parameters:

- **Academic performance**
- **Performance in an online quiz**
- **Participation in science fairs and extracurricular activities**
- **Achievements in Olympiads and sports**
- **Membership in NCC, NSS, or Scouts and Guides**

* Additional weightage is given for rural students. The emphasis on rural participation ensures that talented students from remote areas also get access to world-class learning opportunities

The programme ensures representation from all states and union territories, making the programme inclusive and nationally representative.

Structure and Duration

YUVIKA a two-week residential programme is conducted during the month of May. The residential nature of the programme allows students to immerse themselves fully in a scientific environment, interacting with peers and experts alike.

The programme is hosted at multiple ISRO centres across the country. Starting with 120 students and 5 hosting ISRO Centres in 2019, it has expanded to 456 students and 9 hosting ISRO centres in YUVIKA 2026 edition. Following are the YUVIKA hosting ISRO Centres

- **Vikram Sarabhai Space Centre (VSSC), Thiruvananthapuram**
- **U. R. Rao Satellite Centre (URSC), Bengaluru**
- **Space Applications Centre (SAC), Ahmedabad**
- **Satish Dhawan Space Centre (SDSC), Sriharikota**
- **National Remote Sensing Centre (NRSC), Hyderabad**
- **Indian Institute of Remote Sensing (IIRS), Dehradun**
- **North Eastern Space Applications Centre (NE-SAC), Shillong**
- **Regional Remote sensing Centre (RRSC-West)), Jodhpur**
- **ISRO Propulsion Complex (IPRC), Mahendragiri**

Curriculum and Activities

One of the most distinctive features of YUVIKA is its comprehensive and engaging curriculum. The programme blends theoretical knowledge with practical exposure, making learning both effective and enjoyable. Students attend lectures delivered by ISRO scientists and subject experts. These sessions cover a wide range of topics, including:

- **Basics of space science**
- **Satellite communication**
- **Remote sensing**
- **Rocket propulsion**
- **Space missions and exploration**

Practical learning is a cornerstone of YUVIKA. Students participate in various activities that help them understand scientific concepts through direct application. A few of them is listed below

- **Model rocketry**
- **CANSAT experiments/Robotics and coding exercises**
- **Drone demonstrations**
- **DIY science kits assembly.**
- **SKY Gazing sessions**

Facility Visits

Participants are given guided tours of ISRO's state-of-the-art facilities, including laboratories, launch sites, and research centres of respective hosting Centres. Such visits provide a rare glimpse into the functioning of ISRO.

Interaction with Scientists

Students get the opportunity to interact with experienced scientists, where they ask questions, and gain insights into real-world challenges in space research. This interaction often proves to be one of the most inspiring aspects of the programme.

Extracurricular Activities

In addition to academic sessions, YUVIKA also includes various extracurricular activities which contributes to the holistic development of participants:

- Sky gazing sessions
- Cultural programmes
- Sports and yoga
- Local sightseeing/Industry visits etc

Facilities and Financial Support

One of the most attractive aspects of YUVIKA is that it is fully funded by ISRO. Selected students receive free accommodation and logistics, study materials etc. and travel reimbursement as applicable. This financial support ensures that talented students from all economic backgrounds can participate without any burden.

NE-SPARKS

The North East Students' Programme for Awareness, Reach, and Knowledge on Space (NE-SPARKS) programme is an initiative launched by ISRO, NEC and State Governments of North Eastern region. This programme was conceptualized following the directives of the Honourable Union Home Minister and President of the NESAC Society, Shri Amit Shah. As part of this programme, total 800 students in 8 batches (100 students per batch) from eight states of North East Region visited ISRO Centres in Bengaluru. In the two-day programme students were offered with immersive exposure to cutting-edge space technology and inspiring interactions with eminent scientists and engineers. A visit to UR Rao Satellite Centre (URSC) and ISRO Telemetry Tracking and Command Network was part of the programme.

Students engaged in group activity of NE-SPARK Programme

Students Group of NE-SPARK Programme with Dr. V. Narayanan, Secretary, DOS / Chairman, ISRO

NE students visit ISRO under NE-SPARKS

National Missions on Climate Change

Building India's Scientific Pathway Towards Climate Resilience and Sustainable Development

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Climate change has emerged as one of the defining challenges of the 21st century, influencing ecosystems, economies, human health, food security, and sustainable development across the globe. For a country like India, with its vast geographic diversity, climate-sensitive sectors, and large dependent population, the challenge is particularly complex. The impacts of climate change are visible in the form of erratic monsoons, glacial retreat in the Himalayas, rising temperatures, floods, droughts, coastal vulnerability, biodiversity loss, and increasing frequency of extreme weather events. Recognising the urgency of addressing these challenges through science-based policy and institutional mechanisms, the Government of India launched the National Action Plan on Climate Change (NAPCC) on 30 June 2008.

The NAPCC outlined eight National Missions aimed at promoting sustainable development while simultaneously addressing climate concerns. Among these, two important missions were entrusted to the Department of Science and Technology (DST): the National Mission for Sustaining the Himalayan Ecosystem (NMSHE) and the National Mission on Strategic Knowledge for Climate Change (NMSKCC). These missions were conceived not merely as research programmes, but as long-term national scientific initiatives to build climate knowledge systems, institutional capacities, and evidence-based adaptation strategies for the country.

Unlike several other missions under the NAPCC that evolved around existing sectoral schemes, the DST-led missions had to establish an entirely new scientific architecture dedicated to climate research, adaptation science, vulnerability assessment, and Himalayan ecosystem studies. Over the years, these missions have evolved into powerful national platforms connecting universities, research institutions, policymakers, state governments, communities, and international collaborators.

Today, the outcomes of these missions extend far beyond scientific publications. They have contributed to climate vulnerability mapping, glacier research, adaptation planning, agricultural resilience, public awareness, human health, technology assessments, institutional strengthening, and human resource development. The missions have laid the foundation for India's climate research ecosystem and continue to support the country's vision of climate-resilient growth and sustainable development under the broader framework of "Viksit Bharat 2047".

Mission

The overarching objective of NMSHE and NMSKCC is to strengthen India's scientific and technological capacity for understanding, assessing, and responding to climate change impacts through knowledge generation, institutional development, innovation, and climate adaptation.

The missions aim to:

» **Build strategic scientific knowledge on climate change and its impacts.**

» **Strengthen institutional and human capacities in climate science and adaptation.**

» **Promote interdisciplinary research on climate-sensitive ecosystems and sectors.**

» **Develop evidence-based adaptation and resilience strategies.**

» **Enhance understanding of the Himalayan ecosystem and cryosphere.**

» **Support States and communities in climate vulnerability assessment and adaptation planning.**

» **Foster collaboration among scientific institutions, governments, and international partners.**

» **Promote public awareness and climate literacy across society.**

These missions recognise that climate resilience cannot be achieved through isolated interventions. Instead, it requires an integrated framework involving science, policy, technology, institutions, and community participation. Accordingly, a broad network of Centres of Excellence (CoEs), thematic task forces, major R&D Programme, thematic network programme, State climate change cells, and capacity-building initiatives was established under the missions.

Objectives

1. Building Strategic Knowledge Systems

One of the primary objectives of the missions has been to establish robust scientific knowledge systems capable of addressing the multidimensional aspects of climate change. This includes climate modelling, vulnerability assessment, adaptation science, mitigation strategies, cryosphere studies, biodiversity assessments, and socio-economic impact analysis.

The missions aimed to generate scientific evidence that could support policy decisions and strengthen India's climate preparedness at national, State, and local levels.

2. Strengthening Research and Scientific Institutions

The missions seek to empower universities, research organisations, and scientific institutions across the country by creating dedicated climate research facilities and strengthening interdisciplinary collaboration.

To achieve this, multiple Centres of Excellence and thematic network programmes were established in areas such as:

- **Climate modelling**
- **Coastal vulnerability**
- **Urban climate**
- **Disaster risk reduction**
- **Cryosphere science**
- **Agriculture and climate resilience**
- **Climate and human health**
- **Adaptation strategies**
- **Environmental sustainability**
- **Hydro-climatic extremes**

These institutions became hubs for research, training, innovation, and outreach activities.

3. Sustaining the Himalayan Ecosystem

As one of the most climate-sensitive regions on Earth, the Himalayan ecosystem plays a critical role in regulating the water resources, biodiversity, and ecological balance of South Asia. The NMSHE was custom-designed to monitor glaciers and cryosphere changes, map climate impacts on mountain biodiversity, and study hydrological processes to safeguard vital water resources. Furthermore, the mission prioritizes supporting climate-resilient agriculture and livelihoods for mountain communities, preserving traditional ecological knowledge, and building local scientific capacities within the Himalayan states.

4. Developing Climate Vulnerability and Risk Assessments

Another major objective was to create scientifically robust frameworks for climate vulnerability assessment across India. These assessments were intended to identify vulnerable States, districts, ecosystems, and communities, thereby supporting adaptation planning and resource prioritisation.

The missions also aim to standardise methodologies so that all States could adopt a common framework for climate vulnerability assessment.

5. Human Capacity Building and Skill Development

Long-term climate resilience depends entirely on a highly trained and adaptable workforce. Recognizing this vital human variable, the missions deployed an extensive, multi-layered approach to capacity building and skill development across the country. Rather than focusing solely on isolated training sessions, the initiatives systematically developed human expertise through specialized workshops, intensive summer and winter schools, target-oriented training programmes, and competitive student fellowships.

To bridge the gap between theory and practical fieldwork, the missions integrated hands-on, field-based glacier training alongside dedicated media training programmes and advanced research fellowships designed to foster scientific networking initiatives. The ultimate objective of this sweeping educational blueprint was to create an entirely new generation of scientists, regional administrators, infrastructure planners, and science communicators uniquely equipped with the tools and knowledge required to address India's evolving climate challenges.

6. Supporting Climate Adaptation and Resilience

The missions aimed to support adaptation planning in agriculture, water resources, urban systems, public health, and disaster management. Scientific research under the missions sought to identify adaptation pathways suitable for India's diverse ecological and socio-economic conditions.

Special emphasis was given to climate-resilient technologies, sustainable agriculture, and adaptive development planning.

7. Promoting Technology Assessment and Innovation

Technology Needs Assessment (TNA) initiatives were designed to identify critical technologies for climate mitigation and adaptation across sectors such as:

- **Energy**
- **Transport**
- **Agriculture**
- **Water**
- **Waste management**
- **Industry**
- **Urban infrastructure**

The missions aim to support informed technology deployment and climate-responsive innovation.

8. Technology Innovation & Public Literacy

Through Technology Needs Assessment (TNA) initiatives, the missions evaluate and support informed technology deployment across vital sectors like energy, transport, agriculture, water, waste management, industry, and urban infrastructure.

At the same time, the human element is never forgotten. The missions actively translate high science into public awareness through extensive outreach

campaigns, student competitions, community workshops, radio and television broadcasts, and targeted social media engagement to foster society-wide climate literacy.

Achievements and Outcomes

Establishment of Centres of Excellence

One of the most significant achievements of the missions has been the establishment of 18 CoEs dedicated to climate change research and adaptation science at Indian Institutes of Technology (IIT) at Delhi, Madras, Bombay, Kharagpur and Bananas Hindu University, Indian Institute of Science Bangalore, International Crops Research Institute for the Semi-Arid Tropics (ICRISAT) Hyderabad, and Tamil Nadu Agriculture University etc. These centres have addressed critical gaps in areas such as climate modelling, coastal vulnerability, peri-urban floods, cryosphere science, adaptation strategies, and climate-related health impacts.

These institutions have evolved into key centres for generating scientific knowledge, building research capacity, promoting outreach and awareness, and providing evidence-based support for policymaking

A major milestone was the inauguration of a CoE at ICRISAT by Prime Minister in February 2022, highlighting the national importance of climate-resilient agricultural research.

Advancement of Glacier and Cryosphere Research

Climate change impacts on Himalayan glaciers represent one of the most critical concerns for India's ecological and water security. Under the missions, extensive glacier research programmes were initiated across the Himalayan region.

Key achievements include:

- **Establishment of specialised glaciology centres.**
- **Creation of the second Ice-Core Research Centre in India at the University of Kashmir.**
- **Establishment of a Centre of Excellence at the Indian Institute of Science, Bangalore (or Bengaluru?), University of Kashmir, Tezpur University, Assam, (I think there is a CoE in Tezpur University too – please fact-check) and and Sikkim University.**
- **Creation of a Himalayan Glaciology Centre at the Wadia Institute of Himalayan Geology.**
- **Formation of an Inter-University Consortium involving major universities.**
- **Special training programmes in glaciology at University of Kashmir, including hands-on glacier monitoring exercises in Ladakh and other Himalayan regions.**

Capacity Building Programme in Glaciology

Research conducted under these programmes has significantly improved understanding of glacial retreat, glacier mass loss, snow dynamics, and climate impacts on Himalayan hydrology.

National Climate Vulnerability Mapping

In a historic first, the missions delivered a comprehensive, standardized climate vulnerability assessment at both state and district levels across India. Collaborating institutions like IIT Mandi, IIT Guwahati, and the Centre for Study of Science, Technology and Policy (CSTEP) deployed a common framework anchored in the IPCC Risk and Vulnerability guidelines.

The assessments identified a highly vulnerable eastern corridor, highlighting states such as Jharkhand, Assam, Bihar, Chhattisgarh, Arunachal Pradesh, Mizoram, Odisha, and West Bengal. By extending this assessment down to nearly 690 individual districts, the project has given states a definitive scientific tool to revise their State Action Plans on Climate Change (SAPCCs) and prioritize local adaptation funding.

Strengthening State Climate Change Cells

The establishment of 30 State Climate Change Cells (SCCCs) across India represents a major institutional achievement under the missions.

These cells have strengthened the ability of State governments to:

- **Conduct vulnerability assessments.**
- **Integrate climate concerns into development planning.**
- **Develop adaptation strategies.**
- **Coordinate climate-related programmes.**
- **Build institutional expertise.**

The common framework adopted by the States has ensured consistency and comparability in climate risk assessments across the country.

Expansion of Major R&D Programmes

A total of 39 major R&D programmes has been supported under the missions across universities and research institutions. These programmes cover areas such as:

- **Regional climate modelling**
- **Paleo-climate studies**
- **Forest ecosystems**
- **Hydro-climatic extremes**
- **Geo-engineering**
- **Climate-resilient villages**
- **Adaptation in the Himalayan region**
- **Agriculture**

The programmes have significantly contributed to India's scientific understanding of climate processes and adaptation pathways.

Climate Change and Human Health Research

Launched in 2014, the dedicated National Network Programme on Climate Change and Human Health has expanded rapidly. Research under this banner investigates the explicit links between a changing climate and public health, focusing on vector-borne diseases, heat stress, urban air pollution, water-borne outbreaks, tribal health vulnerabilities, and mental health impacts. The empirical evidence generated here is directly informing national health adaptation strategies and early-warning disease surveillance systems.

The Collaborative Network: International Alliances and Shared Data

Climate change is an inherently borderless challenge, meaning an effective defense requires a fluid exchange of international intellectual capital. A major success of the DST missions has been their ability to seamlessly bridge local field needs with global expertise, forging powerful bilateral alliances that have rapidly accelerated India's climate-science and glaciological capabilities.

Alongside these international partnerships, the missions recognized that data is the ultimate currency of modern science. To ensure these global insights and field discoveries are preserved, the initiatives have funded the creation of a massive, centralized digital data grid. These repositories serve as vital national assets, providing the foundational baseline data required for long-term scientific research, environmental tracking, and evidence-based policy planning across the subcontinent.

International Collaborations

The missions have successfully fostered international scientific collaboration.

Key initiatives include:

Indo-US Fulbright-Kalam Climate Fellowship

Launched in 2016, the fellowship programme supports Indian and American scholars pursuing advanced climate research. It has contributed to long-term research collaboration and scientific exchange.

Indo-German Collaboration

The Indo-German Climate Research Collaboration supported numerous workshops and training programmes involving approximately 1,800 participants.

Indo-Swiss Capacity Building Programme

The programme implemented jointly with the Swiss Agency for Development and Cooperation trained Indian researchers in Himalayan glaciology and cryosphere science.

The programme also developed a comprehensive glaciology curriculum comprising 19 modules covering glacier dynamics, climate impacts, and cryosphere hazards.

Development of Climate Databases

The missions have supported extensive database creation related to:

- Himalayan glaciers
- Biodiversity
- hreatened species
- Alien plant species
- Traditional ecological knowledge
- Hydro-meteorological processes
- Geological resources
- Forest ecosystems

These databases are valuable national assets supporting long-term scientific research and policy planning.

Climate-Resilient Agriculture and Livelihoods

Research and field interventions under the missions have promoted climate-resilient agriculture and livelihood systems in the Himalayan region.

Key outcomes include:

- **Promotion of resilient crop varieties.**
- **Support for sustainable farming practices.**
- **Introduction of improved climate-resilient technologies.**
- **Capacity building for agricultural simulation modelling.**
- **Importantly, climate-resilient interventions directly benefitted:**
- **More than 50,000 farmers**
- **10 self-help groups**
- **200 families across the Himalayan region**
- **These efforts have strengthened local adaptive capacity and livelihood resilience.**

Technology Needs Assessment and Innovation Planning

The Technology Needs Assessment (TNA) initiative supported by Technology Information Forecasting and Assessment Council evaluated technologies across sectors including energy, agriculture, transport, waste, and industry.

Key achievements include:

- **Development of technology fact sheets.**
- **Assessment of technology readiness levels (TRLs).**
- **Stakeholder consultations and workshops.**
- **Preparation of Technology Action Plans** (TAPs).

These outcomes support informed climate technology deployment and low-carbon development pathways.

Public Awareness and Outreach

The missions have undertaken large-scale public engagement initiatives.

Major outcomes include:

- **Nearly 950 awareness programmes conducted.**
- **Approximately 3 lakh stakeholders sensitised.**
- **More than 7.5 lakh students engaged through awareness activities.**
- **Training and fellowship support for media professionals.**
- **Outreach through radio, television, street plays, and social media.**

These initiatives have strengthened climate literacy and public participation in climate action.

Building National Climate Research Network and Knowledge Generation

One of the most enduring achievements of the missions has been the creation of a collaborative climate research network involving:

- **Over 2,000 researchers engaged across climate change thematic areas**
- **More than 450 institutions, universities, and organisations connected through the nationwide climate research network**
- **Participation from 34 States and Union Territories enabling pan-India collaboration and coordinated climate action.**
- **More than 2,000 research papers published under various projects of the Climate Change Programme.**
- **Over 1,000 reports, monographs, articles, conference proceedings, brochures, and posters disseminated.**
- **Development of 72 new techniques and methodologies in climate science and adaptation research.**
- **Around 1,000 research fellows and nearly 600 scientific and technical staff deployed across projects and institutions.**
- **More than 1,29,000 people benefitted through training programmes and public awareness initiatives.**
- **Capacity building and awareness generation conducted for over 5.2 lakh school and undergraduate students through quizzes, painting competitions, and related activities.**

This nationwide network has facilitated interdisciplinary collaboration, knowledge exchange, and coordinated climate research across India.

The National Mission for Sustaining the Himalayan Ecosystem (NMSHE) and the National Mission on Strategic Knowledge for Climate Change (NMSKCC) represent pioneering scientific initiatives in India's climate governance architecture. Over the years, these missions have successfully built institutional capacities, advanced climate science, empowered researchers, supported states in adaptation planning, and generated critical strategic knowledge for climate resilience.

Their achievements demonstrate that climate action is not limited to mitigation alone. It requires sustained investments in science, institutions, human resources, technology, and public engagement. Through glacier research, vulnerability assessments, climate-resilient agriculture, capacity building, and collaborative scientific networks, the missions have laid the foundation for evidence-based climate governance in India.

As India moves toward the vision of "Viksit Bharat 2047," these missions will continue to play a pivotal role in shaping a resilient, sustainable, and climate-secure future. The scientific ecosystem developed under these missions is not only strengthening India's national preparedness but also contributing to global climate knowledge and sustainable development efforts.

The journey ahead will require deeper integration of science with policy, stronger community participation, innovative technologies, and sustained international cooperation. The achievements under NMSHE and NMSKCC clearly demonstrate that India possesses the scientific capability, institutional commitment, and collaborative spirit necessary to address the challenges of climate change while safeguarding ecological sustainability and human well-being for future generations.

Two Decades of GOOD LABORATORY PRACTICE (GLP) Programme in India: BUILDING GLOBAL CREDIBILITY IN SAFETY TESTING

AI-Generated image

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The reliability and credibility of scientific data form the cornerstone of regulatory decision-making in sectors such as pharmaceuticals, agrochemicals, industrial chemicals, cosmetics, food additives, and medical devices. Regulatory authorities across the world rely heavily on non-clinical safety studies to assess potential risks associated with chemical substances before they are introduced into the market or environment. In such a context, ensuring that safety studies for these chemical substances are conducted according to internationally accepted quality standards becomes critically important.

Good Laboratory Practice (GLP) provides a globally recognised quality system that governs the organisational processes and conditions under which non-clinical health and environmental safety studies are planned, performed, monitored, recorded, reported, and archived. Over the past two decades, India has successfully developed and implemented a robust national framework for compliance with the OECD Principles of GLP. Spearheaded by the Department of Science and Technology (DST), Government of India, the National GLP Programme has enabled Indian laboratories/ test facilities to generate safety data that are widely accepted by regulatory authorities worldwide.

India's journey in establishing a credible GLP ecosystem reflects a sustained commitment to strengthening regulatory science, improving research quality, and facilitating international trade. The development of the programme has also demonstrated the importance of strong institutional mechanisms, international collaboration, and continuous capacity building.

GLP within the Broader GxP Quality Ecosystem

The Good Practice (GxP) framework represents an integrated quality ecosystem that governs the entire lifecycle of regulated products, from research and development to manufacturing, distribution, clinical

evaluation and post-market surveillance. It encompasses Good Laboratory Practice (GLP), Good Manufacturing Practice (GMP), Good Clinical Practice (GCP), Good Pharmacovigilance Practice (GVP), Good Distribution Practice (GDP) and Good Documentation Practice (GDocP), each addressing a critical component of quality, safety, efficacy and data integrity. Within this broader GxP architecture, GLP serves as a foundational pillar by ensuring the quality and reliability of non-clinical safety data, thereby supporting subsequent stages of product development and regulatory decision-making. Together, these interconnected quality systems function as a coordinated framework that strengthens regulatory confidence, promotes global harmonisation, and supports innovation-driven growth.

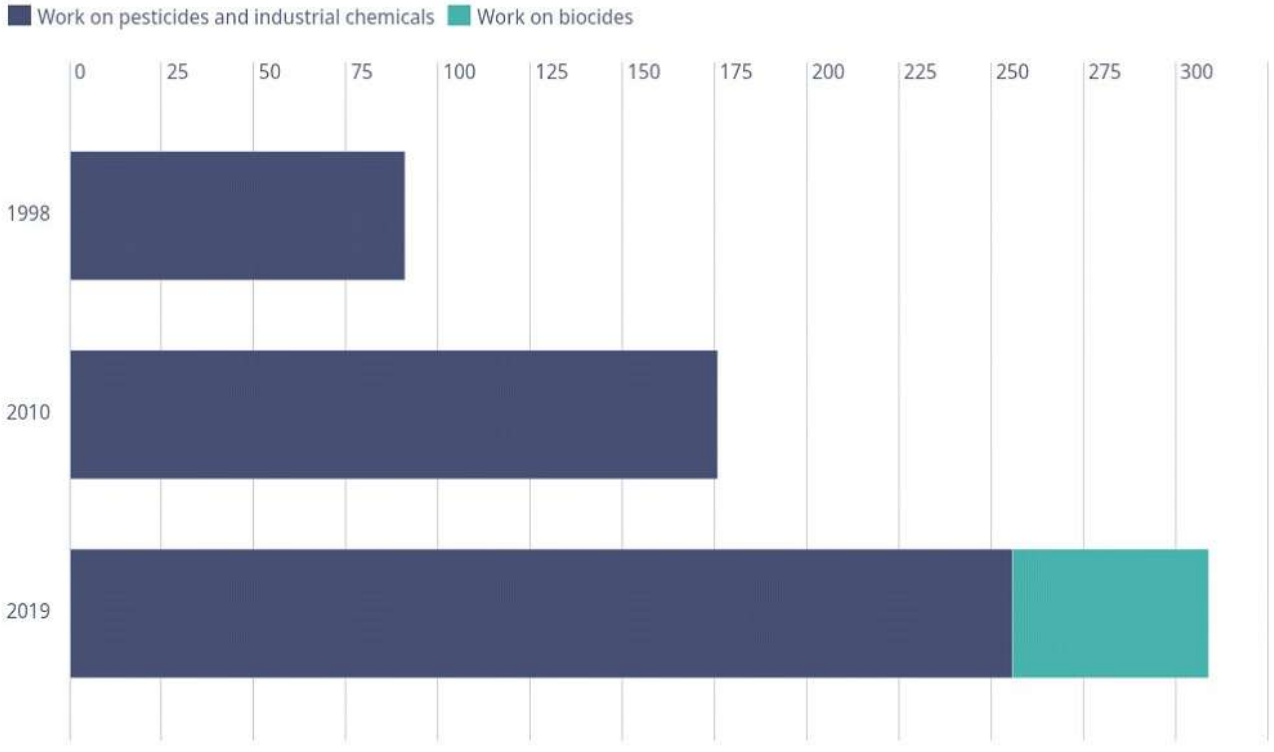
The Global Framework of Good Laboratory Practice

The concept of Good Laboratory Practice (GLP) emerged in the late 1970s in response to growing concerns regarding the reliability and integrity of safety data generated by laboratories involved in regulatory testing. These concerns were heightened by several cases of laboratory misconduct, most notably the Industrial Bio-Test (IBT) scandal, which exposed widespread falsification of non-clinical safety data for pharmaceuticals, pesticides, and industrial chemicals. Prior to the introduction of GLP, many non-clinical safety studies submitted to regulatory authorities suffered from inadequate planning, poor documentation, inconsistent laboratory practices, and, in some cases, manipulation of raw data, making it difficult for regulators to verify the validity and reproducibility of study findings.

To address these concerns, the U.S. Food and Drug Administration (FDA) established the first Good Laboratory Practice (GLP) regulations in 1978, followed by similar regulations issued by the U.S. Environmental Protection Agency (EPA) in 1983. Subsequently, to facilitate international harmonisation and the mutual acceptance of non-clinical safety data across countries, the Organisation for Economic Co-operation and Development (OECD) developed internationally harmonised GLP Principles. These principles provide comprehensive guidance on the organisation and management of laboratories conducting non-clinical safety studies. They define requirements related to personnel responsibilities, laboratory facilities, equipment maintenance, standard operating procedures, study protocols, quality assurance systems, data recording, reporting, and the archiving of records, thereby ensuring the quality, integrity, traceability, and reliability of safety data used in regulatory decision-making.

Savings to governments and industry as a result of OECD environmental health and safety work

In millions euros



Notes: Figures have been adjusted for inflation

Source: OECD. Saving Costs in Chemicals Management: How the OECD Ensures Benefits to Society. OECD Publishing

A key feature of the OECD framework is the Mutual Acceptance of Data (MAD) system. Under this arrangement, safety data generated in GLP-compliant laboratories in one adhering country are accepted by regulatory authorities in other participating countries. The MAD system has significantly streamlined global regulatory processes by eliminating the need for duplicate testing in multiple countries.

The benefits of the MAD system are substantial. It reduces the cost and time required for regulatory approvals, avoids unnecessary use of laboratory animals in repeat studies, and facilitates international trade in regulated products. For countries with strong research and manufacturing capabilities, participation in the MAD system provides an important opportunity to integrate with the global regulatory science ecosystem.

As per the OECD's publication the net financial savings to governments and industry brought by the programme (after deducting costs) for harmonising the testing and assessment of new biocides, new and existing industrial chemicals, and pesticides, are estimated to be more than EUR 309 million a year.

Establishment of the National GLP Programme in India

Recognising the strategic importance of internationally credible safety data, the Government of India took an important step in establishing the National GLP Compliance Monitoring Authority (NGCMA) in 2002 under the aegis of the Department of Science and Technology. The creation of the NGCMA marked the beginning of a systematic effort to align India's laboratory practices with international GLP standards.

The NGCMA functions as the national authority responsible for monitoring compliance with OECD GLP principles and for certifying laboratories that conduct non-clinical safety studies. Its core responsibilities include inspection of test facilities, evaluation of quality systems, certification of GLP compliance, and periodic surveillance of certified laboratories.

The programme operates through a well-defined governance structure. An Apex Body (GLP Authority) chaired by the Secretary, DST provides overall policy direction and oversight. The Apex Body includes representation from all stakeholder ministries and regulatory agencies, including those responsible for pharmaceuticals, chemicals, agriculture, and environmental regulation. This inter-ministerial framework ensures coordination between scientific research, regulatory requirements, and industrial development.

The Technical Committee on GLP serves as the scientific and technical advisory body of the National GLP Compliance Monitoring Authority (NGCMA), providing expert guidance on the implementation and continual strengthening of the GLP programme in India. Comprising eminent experts from academia, research institutions, regulatory bodies, and industry, the Committee evaluates technical aspects of GLP implementation, reviews inspection findings and certification recommendations, advises on policy and procedural improvements, and facilitates harmonisation with evolving OECD GLP requirements. Through its multidisciplinary expertise, the Technical Committee plays a pivotal role in maintaining the scientific integrity, transparency, and international credibility of India's GLP compliance monitoring system.

The NGCMA conducts detailed inspections of laboratories seeking GLP certification. These inspections assess the organisational structure, quality assurance mechanisms, personnel qualifications, facilities, equipment calibration systems, documentation procedures, and archival arrangements. Only laboratories that demonstrate full compliance with OECD GLP principles are granted certification.

Over a period of around two and a half decades, a rigorous and transparent compliance monitoring system has been established, supported by a trained pool of GLP inspectors drawn from leading academic, scientific and research institutions across the country.

India's Entry into the OECD's Mutual Acceptance of Data System

One of the most significant milestones in the development of India's GLP programme was achieved in March 2011, when the country became a full adherent to the OECD MAD system. This recognition followed a comprehensive international evaluation of India's GLP compliance monitoring system by OECD experts.

The successful evaluation confirmed that India's GLP monitoring framework met the stringent requirements of the OECD. As a result, safety studies conducted in GLP-certified laboratories in India became acceptable to regulatory authorities in all OECD member countries and other MAD-adhering economies.

The OECD MAD system is a multilateral agreement which ensures quality data for regulatory decision-making while saving governments and chemical producers over EUR 309 million every year by facilitating the sharing of the results of a variety of non-clinical safety studies done on chemicals.

The OECD MAD system requires that testing be carried out using OECD standards for test methods (OECD Test Guidelines) and for data quality and integrity (OECD Principles of Good Laboratory Practice - GLP).

India's entry into the MAD system has had far-reaching implications for the country's research and industrial sectors. Indian laboratories are now able to generate safety data that is recognised internationally, thereby reducing the need for duplicate testing abroad. This has significantly lowered the cost and time associated with regulatory approvals for different chemical substances including pharmaceuticals, agrochemicals, and industrial chemicals developed in India.

The OECD MAD system is a highly effective multilateral agreement that harmonizes chemical safety testing across 45 participating nations globally. This framework legally binds all 38 official OECD member countries including major industrialized economies like the United States, Japan, and Germany along with 7 non-member OECD MAD adherent economies, including economic powerhouses like India, Brazil, and Singapore.

Key Milestones of India's GLP Programme

2002 – Establishment of NGCMA

The Government of India established the National GLP Compliance Monitoring Authority (NGCMA) under the Department of Science and Technology to oversee the implementation and monitoring of Good Laboratory Practice standards in the country.

2003–2010 – Development of National GLP Infrastructure

India developed its GLP compliance monitoring framework, trained inspectors, and initiated certification of test facilities conducting non-clinical safety studies in accordance with OECD principles, representatives from India attended all meetings of the OECD's Working Group on GLP (now the Working Party on GLP) with an "Observer" status.

2011 – India Joins OECD Mutual Acceptance of Data (MAD) System

India became a full adherent to the OECD MAD system, enabling safety data generated in GLP-certified laboratories in India to be accepted by regulatory authorities across OECD member countries and other adhering economies.

2010s – Expansion of GLP-Certified Test Facilities

The number of GLP-certified laboratories steadily increased across government institutions, academic organisations, and private sector facilities, strengthening India's capabilities in regulatory safety testing. This also gave a boost to the export of chemicals from the country.

Strengthening International Engagement

India actively participates in the OECD Working Party on GLP, contributing to international regulatory discussions and sharing best practices in compliance monitoring.

Capacity Building and Training

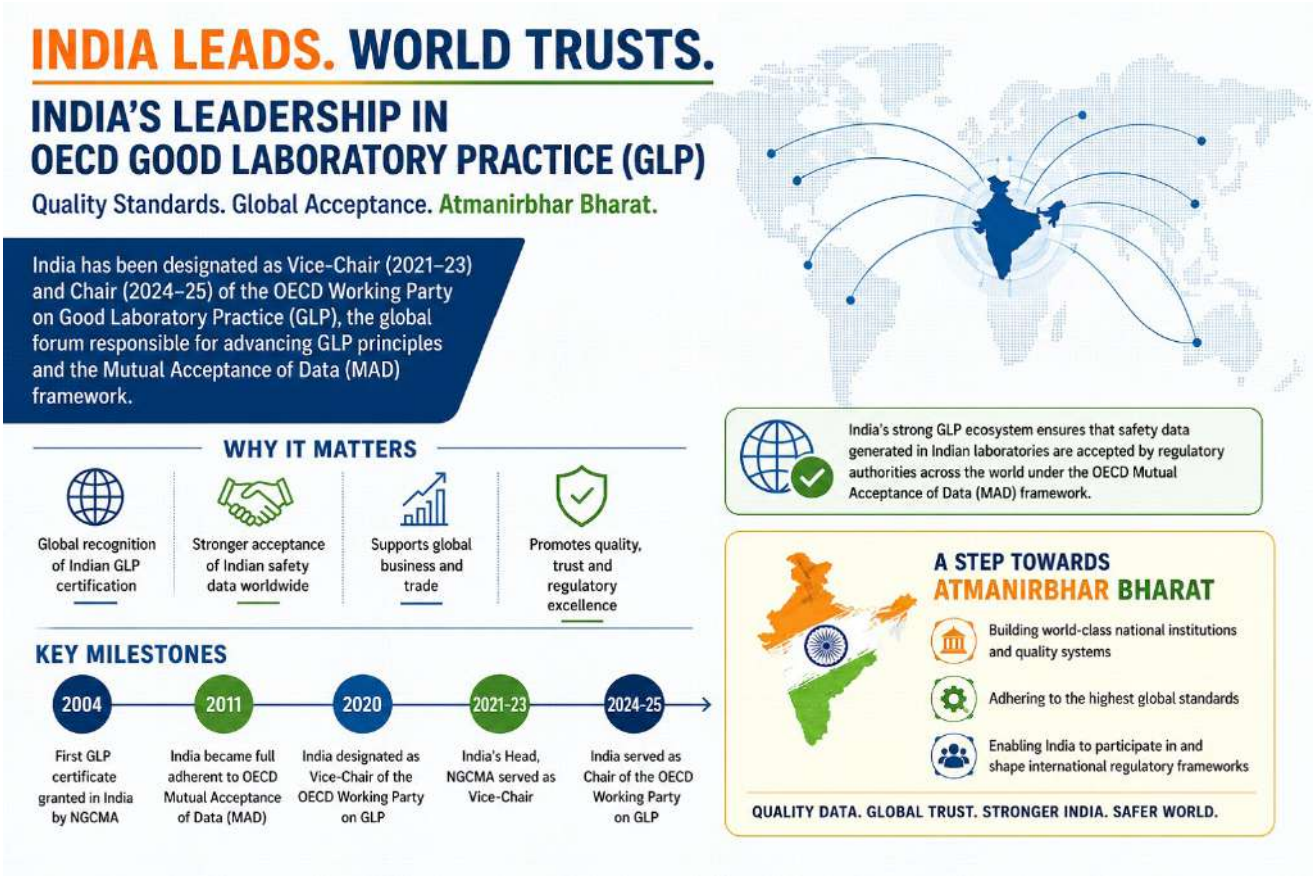
Regular training programmes, inspector workshops, and awareness initiatives have been organised to strengthen GLP implementation and develop a strong ecosystem of regulatory scientists and quality assurance professionals.

Global Recognition of India's GLP Programme

India's GLP monitoring system is internationally recognised for its robustness and transparency, supporting the country's growing role in global safety assessment studies. Based on India's contributions to the activities of OECD's Working Party (WP) on GLP, Head NGCMA was designated to work on the Bureau of the WP for five years, as the Vice Chair (during 2021-23) and the Chair (during 2024-25)

Expansion of GLP Test Facilities in India

Since the establishment of the national GLP programme, India has witnessed steady growth in the number and diversity of GLP-certified laboratories. These facilities are located across government research institutions, academic organisations, and private sector laboratories.



This leadership has enhanced confidence in the quality of GLP certification granted by India, strengthened the global acceptance of safety data generated by Indian laboratories, and reinforced India's position as a trusted partner in international regulatory science. Equally important, it exemplifies the vision of Atmanirbhar Bharat—building world-class national institutions and quality systems that meet the highest global standards, enabling India not only to participate in but also to shape international regulatory frameworks.

The recognition has also strengthened India's reputation as a reliable destination for high-quality non-clinical safety studies. Several multinational companies and research organisations now collaborate with GLP-certified Indian laboratories for conducting regulatory safety studies.

The studies conducted in GLP-certified laboratories cover a wide range of scientific disciplines relevant to safety evaluation. These include toxicology studies, mutagenicity and genotoxicity testing, environmental toxicity assessments, residue studies, analytical chemistry, and physical-chemical characterisation of substances.

The expansion of GLP-certified facilities has contributed significantly to strengthening India's capacity for regulatory science. It has also encouraged laboratories to upgrade infrastructure, adopt advanced instrumentation, and implement rigorous quality assurance systems.

Such improvements have had broader benefits for the national research ecosystem by promoting higher standards of scientific documentation, data integrity, and laboratory management.

India, as Chair of the OECD Working Party on Good Laboratory Practice (2024–25), leading global efforts to strengthen regulatory science, foster international collaboration, and promote the Mutual Acceptance of Data (MAD) framework

Capacity Building and Human Resource Development

Capacity building has been a central component of the national GLP programme. Implementing GLP requires not only modern laboratory infrastructure but also a workforce that is trained in quality systems, regulatory requirements, and scientific best practices.

The NGCMA has therefore placed strong emphasis on training and awareness programmes. Over the years, numerous workshops, training sessions, and orientation programmes have been organised for scientists, laboratory managers, study directors, and quality assurance professionals.

A key aspect of this effort has been the development of a cadre of trained GLP inspectors. These inspectors play a crucial role in evaluating laboratories seeking GLP certification and in conducting periodic surveillance inspections of certified facilities. The inspectors are drawn from experienced scientists working in national laboratories, universities, and research institutions.

Role of the National GLP Compliance

Monitoring Authority (NGCMA)

The National GLP Compliance Monitoring Authority (NGCMA), established under the Department of Science and Technology (DST), Government of India, serves as the national body responsible for implementing and monitoring compliance with the principles of Good Laboratory Practice in the country. The authority plays a critical role in ensuring that non-clinical safety studies conducted in Indian laboratories meet internationally accepted quality standards.

Key functions of NGCMA include

Certification of GLP Test Facilities
NGCMA evaluates laboratories conducting non-clinical safety studies and grants GLP certification to facilities that demonstrate compliance with OECD GLP principles.

Inspection and Compliance Monitoring
The authority conducts periodic inspections and surveillance audits of GLP-certified laboratories to ensure continued adherence to quality standards.

Capacity Building and Training
NGCMA organises training programmes, workshops, and awareness initiatives for scientists, laboratory personnel, and inspectors to promote the adoption of GLP principles across the research ecosystem.

Development of a National Inspection System
The authority maintains a trained pool of GLP inspectors drawn from leading scientific/ academic institutions who support the evaluation and monitoring of test facilities.

International Coordination
NGCMA represents India in international forums, including the OECD Working Party on GLP, and facilitates cooperation with GLP monitoring authorities in other countries.

Capacity-building initiatives and inspector training under the GLP Programme

Through these activities, the NGCMA has played a central role in establishing a credible national framework for laboratory quality systems and in enabling the global acceptance of safety data generated in India.

Such capacity-building initiatives have helped create a strong network of professionals who understand both the scientific and regulatory aspects of GLP compliance.

India's Engagement with the International GLP Community

India's GLP programme has evolved in close collaboration with the international GLP community. Active participation in global forums has been essential for keeping the national programme aligned with evolving international standards and practices.

India actively participates in the annual meetings of the OECD Working Party on GLP, where member countries and adhering economies discuss issues related to inspection procedures, regulatory harmonisation, and emerging scientific developments. These interactions provide valuable opportunities to exchange experiences and best practices with GLP monitoring authorities from across the world.

India's contributions to these discussions have been widely appreciated. The country's experience in building a credible GLP monitoring system in a large and diverse scientific ecosystem offers useful insights for other nations seeking to strengthen their regulatory science frameworks.

The Road Ahead

While the National GLP programme has achieved significant milestones over the past two decades, new challenges and opportunities continue to emerge. Advances in biotechnology, nanotechnology, and computational toxicology are transforming the landscape of safety assessment. At the same time, regulatory authorities worldwide are increasingly emphasising data integrity, transparency, and reproducibility in scientific research.

In this evolving environment, the GLP programme in India will continue to focus on several key priorities. These include expanding the network of GLP-certified laboratories, strengthening inspection systems through risk-based assessments, and promoting awareness of GLP principles across the research community through its capacity building initiatives.

Looking ahead, capacity building will remain a key pillar of India's GLP programme. As highlighted in a Press Information Bureau (PIB) release dated 25 July 2022, strengthening the competency of GLP inspectors

Dr Ekta kapoor, Head, Good Laboratory Practices, DST briefed about the programme and its achievements and future plans

and expanding the pool of skilled professionals is essential for positioning India as a global leader in GLP. Continued investment in inspector training, refresher programmes, adoption of emerging scientific and digital tools, and enhancement of institutional capabilities will further strengthen the National GLP Compliance Monitoring Authority (NGCMA).

There is also growing interest in integrating emerging scientific methodologies with GLP-compliant frameworks. Alternative testing methods, in vitro models, and advanced analytical technologies are expected to play a larger role in safety evaluation in the coming years.

Continued collaboration between government agencies, research institutions, and industry within the country will be essential to ensure that India remains at the forefront of regulatory science.

Concluding Remarks

Over the past two decades, the Good Laboratory Practice (GLP) Programme in India has evolved into a robust and internationally recognised system for ensuring the quality and reliability of non-clinical safety studies. Through the establishment of the National GLP Compliance Monitoring Authority and alignment with OECD Principles of GLP, India has strengthened the credibility of its laboratories, enabled international acceptance of safety data, and enhanced the global competitiveness of Indian industry. The programme has also contributed significantly to the development of regulatory science expertise, quality assurance systems and institutional capacity across the country and has laid the foundation for a modern regulatory science ecosystem capable of supporting innovation while maintaining high standards of quality and safety.

The impact of the programme extends far beyond GLP-certified facilities. By promoting internationally harmonised quality systems and evidence-based approaches, it has contributed to strengthening India's scientific infrastructure, regulatory preparedness and policy-making capabilities in areas related to health, agriculture, chemicals and environmental protection.

The programme also supports the broader objectives of the United Nations Sustainable Development Goals by fostering responsible innovation, strengthening scientific capacity, promoting environmental stewardship and contributing to the protection of human health.

The experience of the National GLP Programme demonstrates how sustained policy support, institutional leadership and stakeholder collaboration can create long-term national capacity and global credibility.

As GxP frameworks assume increasing importance in the knowledge and innovation economy, the National GLP Programme stands as a model of quality-led institution building that contributes to the vision of Viksit Bharat 2047.

A strong regulatory science ecosystem is fundamental to a developed nation. India's GLP programme has established internationally accepted standards of quality and integrity, contributing significantly to the vision of Viksit Bharat through safe, credible, and globally recognised science

National Green Hydrogen Mission

Powering India's Next Green Industrial Revolution

Dr Ranjith Krishna Pai

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Department of Science & Technology
Government of India

A New Energy Chapter for India

Imagine an India where steel plants operate without coal, fertilisers are produced without imported natural gas, trucks traverse highways powered by hydrogen fuel cells, ships sail with green methanol, and industries derive energy from sunlight stored in the form of hydrogen molecules.

A decade ago, such a vision might have appeared aspirational. Today, it is steadily becoming reality.

The twenty-first century is witnessing an unprecedented global energy transition driven by climate imperatives, technological advancements, and geopolitical considerations. Nations across the world are actively seeking pathways to decarbonise their economies while ensuring energy security and industrial competitiveness. While renewable electricity generated from solar and wind has emerged as the backbone of clean energy systems, certain sectors remain inherently difficult to electrify. High-temperature industrial processes, chemical feedstocks, long-haul transportation, shipping, and aviation require energy carriers capable of storing and transporting large amounts of energy in a flexible and dispatchable form.

> **Green hydrogen is more than a clean fuel. It is a strategic enabler for India's energy independence, industrial decarbonisation, technological self-reliance, and sustainable economic growth.**

Green hydrogen has therefore emerged as one of the most promising solutions for addressing these challenges.

Hydrogen itself is not a new industrial commodity. It has been used for decades in petroleum refining, fertiliser production, and chemical industries. However, the overwhelming majority of hydrogen produced globally is generated through fossil-fuel-based processes, resulting in substantial greenhouse gas emissions. Green hydrogen, produced by splitting water using renewable electricity, offers a clean and sustainable alternative capable of decarbonising hard-to-abate sectors while complementing renewable energy systems.

Recognising this transformative potential, the Government of India launched the **National Green Hydrogen Mission (NGHM)** in January 2023 with an initial outlay of ₹19,744 crore. The Mission represents one of the world's most comprehensive and ambitious national hydrogen programmes and is expected to become a cornerstone of India's clean energy transition.

More importantly, the Mission is not merely an environmental initiative. It embodies India's aspiration to become a global leader in next-generation clean energy technologies, strengthen domestic manufacturing capabilities, reduce dependence on imported fossil fuels, and establish itself as a competitive exporter of green molecules and associated technologies. By 2030, the Mission is expected to catalyse investments exceeding ₹8 lakh crore, generate more than 6 lakh green jobs, establish at least 5 million metric tonnes per annum (MMTPA) of green hydrogen production capacity, enable approximately 125 GW of dedicated renewable energy capacity, and avoid nearly 50 million tonnes of carbon dioxide emissions annually. The NGHM thus stands at the confluence of India's climate commitments, industrial ambitions, scientific capabilities, and the vision of Viksit Bharat 2047.

Why Hydrogen Matters?

India's economic growth and industrial expansion have historically relied heavily on fossil fuels. The country currently imports nearly 40 per cent of its primary energy requirements, exposing critical sectors to international price fluctuations and supply chain uncertainties. In 2025–26, India's renewable energy installed capacity surpassed 274 GW, accounting for more than half of the total installed electricity generation capacity. Despite these impressive achievements, decarbonising sectors such as steel, cement, fertilisers, chemicals, heavy transport, and shipping remains challenging.

Hydrogen provides a unique opportunity to bridge this gap.

India currently consumes approximately 5-6.5 million tonnes of hydrogen annually, almost entirely in the form of grey hydrogen produced through steam methane reforming of natural gas. Nearly 99 per cent of this hydrogen is utilised in petroleum refining and ammonia synthesis for fertiliser production. Transitioning from grey hydrogen to green hydrogen can significantly reduce carbon emissions while simultaneously improving energy security.

Green hydrogen offers several strategic advantages:

- **Reducing dependence on imported fossil fuels**
- **Enhancing national energy security**
- **Supporting industrial decarbonisation**
- **Promoting indigenous manufacturing**
- **Creating high-value employment opportunities**
- **Enabling exports of green ammonia, methanol, and synthetic fuels**
- **Facilitating large-scale renewable energy integration**

For India, green hydrogen is not merely another energy vector. It is increasingly being viewed as a strategic resource capable of underpinning future industrial growth and technological competitiveness.

National Green Hydrogen Mission Vision and Objectives

The NGHM has been designed as an integrated ecosystem development programme with the overarching objective of making India a global hub for green hydrogen production, utilization, and export.

The Mission seeks to address several interconnected priorities.

Establishing India as a Global Green Hydrogen Hub

India possesses some of the world's most competitive renewable energy tariffs, abundant solar and wind resources, an expanding industrial base, and a growing manufacturing ecosystem. Leveraging these advantages, the Mission aims to position India among the leading producers and exporters of green hydrogen and its derivatives.

India's Green Hydrogen Mission at a Glance

Supporting Industrial Decarbonisation

The Mission prioritises replacing existing grey hydrogen consumption in refining and fertiliser sectors while enabling the use of green hydrogen in steel manufacturing, mobility applications, maritime transport, and emerging industrial sectors.

Strengthening Domestic Manufacturing

A major emphasis has been placed on developing indigenous manufacturing capabilities for electrolysers, fuel cells, catalysts, membranes, storage systems, compressors, and other components of the hydrogen value chain. Such efforts align closely with the vision of Atmanirbhar Bharat and are expected to enhance long-term technological sovereignty.

Accelerating Research and Innovation

Recognising the importance of scientific leadership, the Mission includes dedicated support for research, pilot demonstrations, testing facilities, standards development, and skill creation. Investments in these areas are expected to accelerate technology maturation and facilitate commercialization.

Generating Employment and Economic Opportunities

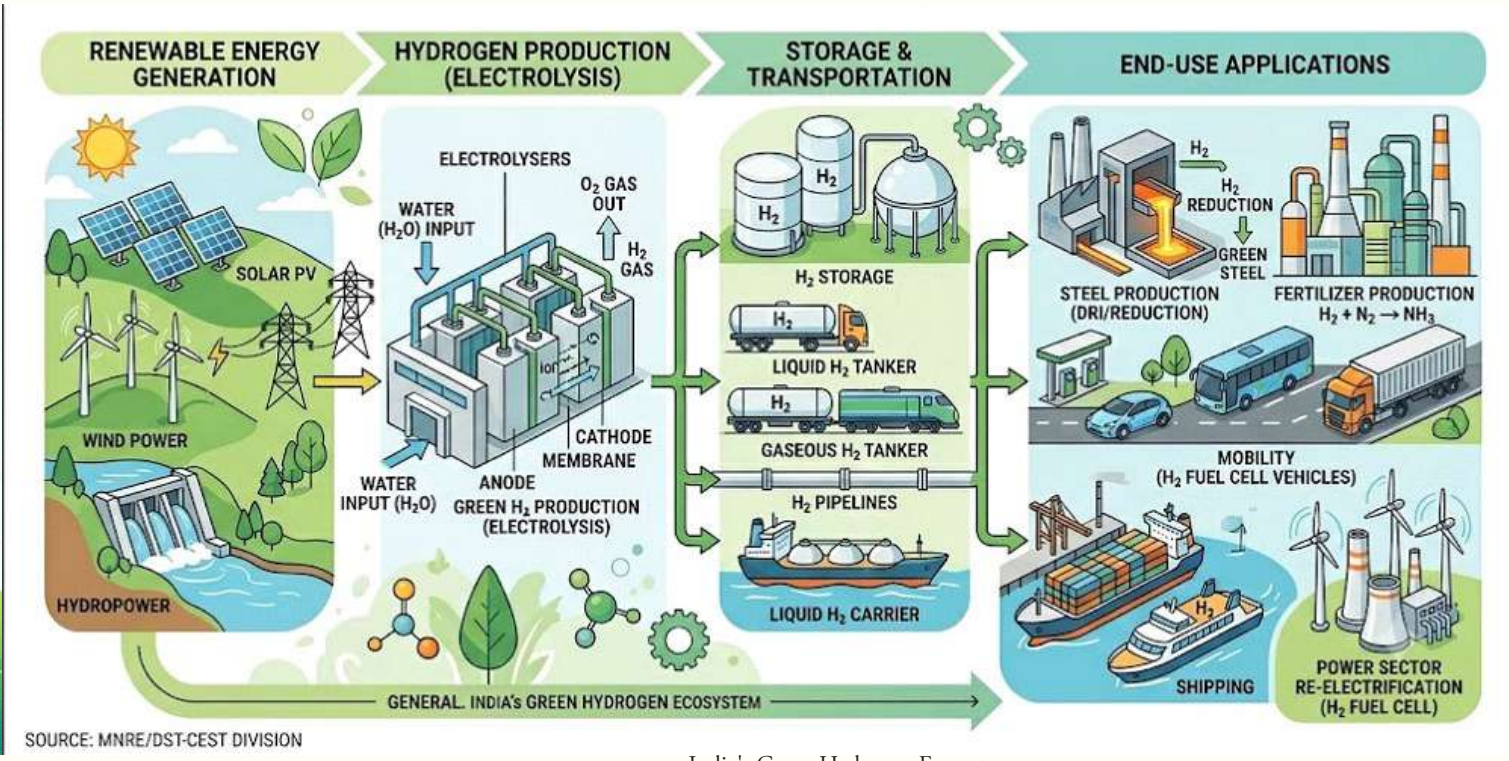
The Mission is projected to generate more than six lakh direct and indirect jobs across manufacturing, engineering, operations, maintenance, logistics, and associated services. Emerging hydrogen ecosystems are also expected to provide opportunities for startups, small and medium enterprises, and innovation-driven businesses.

From Vision to Scale: Building India's Green Hydrogen Ecosystem

Major Achievements under the NGHM

Within a relatively short period since its launch in January 2023, the National Green Hydrogen Mission has progressed decisively from policy formulation to implementation. The Mission is rapidly translating strategic intent into commercially viable projects, manufacturing investments, and large-scale deployment initiatives. One of the Mission's greatest strengths lies in its integrated approach. Rather than focusing solely

Illustration depicting renewable energy generation, electrolysers, hydrogen production, storage, transportation, and end-use applications in steel, fertilisers, mobility, shipping, and power sectors.



India's Green Hydrogen Ecosystem

on hydrogen production, the Mission simultaneously addresses manufacturing, demand creation, research and development, certification, standards, pilot projects, skilling, infrastructure development, and market mechanisms.

Several notable milestones have already been achieved.

Under the Mission, incentives have been awarded for approximately 3 GW per annum of electrolyser manufacturing capacity, laying the foundation for a robust domestic manufacturing ecosystem. Furthermore, around 862,000 tonnes per annum of green hydrogen production capacity have been allocated through competitive bidding processes.

Significant progress has also been made in green ammonia deployment. Approximately 724,000 tonnes per annum of green ammonia capacity have been tendered, and Green Ammonia Purchase Agreements (GAPAs) amounting to nearly 670,000 tonnes per annum have already been signed.

Pilot projects are being implemented in petroleum refineries, while draft guidelines for green methanol production have been released to support future decarbonisation pathways in shipping and chemical sectors. Collectively, these developments indicate that India's hydrogen economy is no longer confined to policy discussions. It is steadily evolving into a commercially relevant industrial ecosystem.

Strategic Interventions for Green Hydrogen Transition (SIGHT): The Financial Backbone of the Mission

The **Strategic Interventions for Green Hydrogen Transition (SIGHT)** programme constitutes the largest component of the NGHM. With a dedicated allocation of **₹17,490 crore**, SIGHT aims to reduce production costs, accelerate manufacturing capacities, create market demand, and improve investor confidence.

The programme is structured around two major components.

Component I: Electrolyser Manufacturing

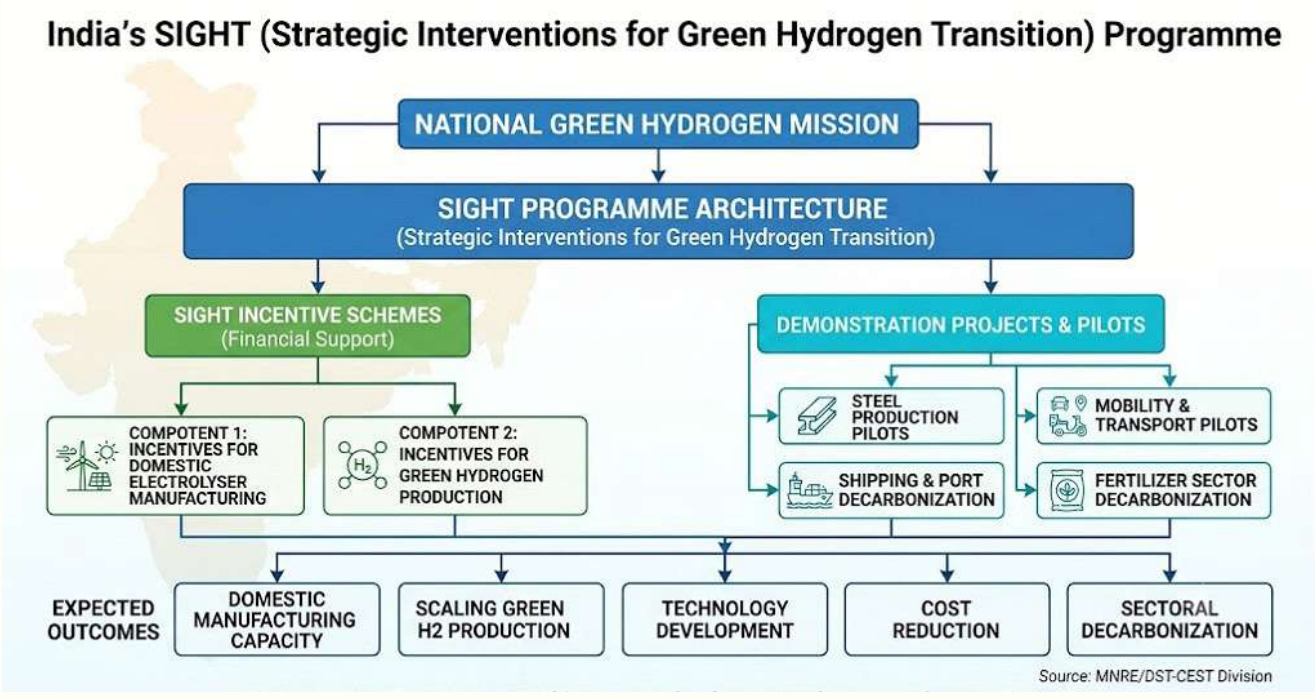
The first component focuses on promoting domestic manufacturing of electrolysers, which are the heart of green hydrogen production systems.

An outlay of approximately **₹4,440 crore** has been earmarked to support electrolyser manufacturing.

The programme encourages:

- **Alkaline electrolysers**
- **PEM electrolysers**
- **Solid oxide electrolysers**
- **Indigenous stack technologies**
- **Local value addition**

Overview of Component-I and Component-II of the SIGHT Scheme, illustrating incentives for electrolyser manufacturing, green hydrogen production, green ammonia, refinery applications, and emerging green methanol initiatives.



SIGHT Programme Architecture under the National Green Hydrogen Mission

The awarded capacities have stimulated announcements of several gigawatt-scale manufacturing facilities by Indian companies, strengthening the country's prospects of becoming an important global electrolyser supplier.

Component II: Green Hydrogen Production

The second component of SIGHT supports the production of green hydrogen and its derivatives.

It adopts a technology-neutral approach while maintaining stringent environmental standards.

Eligible pathways include:

- **Water electrolysis powered by renewable electricity;**
- **Biomass-based hydrogen production;**
- **Emerging low-carbon production routes.**

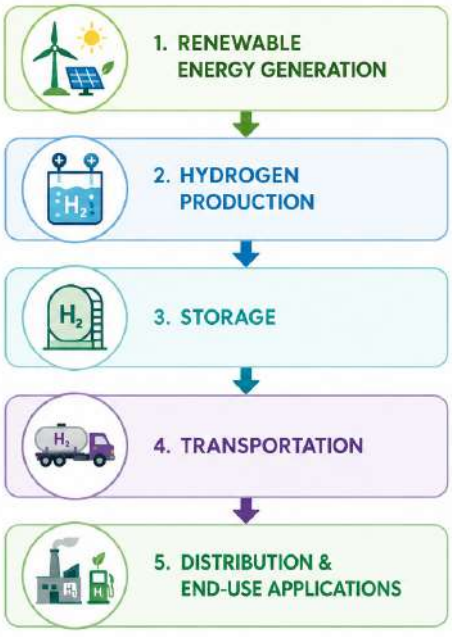
The component seeks to create economies of scale, reduce the levelized cost of hydrogen, and facilitate long-term offtake agreements.

The Government aims to reduce hydrogen production costs toward **USD 12 per kilogram by 2030,** making Indian hydrogen highly competitive in global markets.

Hydrogen Valley Innovation Clusters: India's Living Laboratories

One of the most innovative initiatives emerging under the NGHM is the establishment of Hydrogen Valley Innovation Clusters (HVICs). Hydrogen Valleys integrate the complete hydrogen value chain within geographically concentrated ecosystems.

They bring together:



The concept has gained global recognition through the **Mission Innovation Hydrogen Valley Platform**, which now hosts more than one hundred hydrogen valleys worldwide.

India has approved four Hydrogen Valley Innovation Clusters.

1. **Kerala Hydrogen Valley**
   Lead Institution: ANERT
2. **Odisha Hydrogen Valley**
   Lead Institution: IIT Bhubaneswar
3. **Pune Hydrogen Valley**
   Lead Institution: CSIR-NCL
4. **Jodhpur Hydrogen Valley**
   Lead Institution: IIT Jodhpur

Hydrogen Valleys are expected to demonstrate applications in:

- **Green steel**
- **Green ammonia**
- **Heavy mobility**
- **Mining transportation**
- **Hydrogen-natural gas blending**
- **Waterways**
- **Industrial decarbonisation**
- **Distributed energy systems**

Hydrogen Valleys are anticipated to become catalysts for regional economic growth, startup ecosystems, technology transfer, and industrial innovation.

The Department of Science and Technology (DST) has played an important role in conceptualizing and supporting these integrated hydrogen ecosystems, recognising their potential to accelerate commercialization and bridge the gap between laboratory research and industrial deployment.

Department of Science and Technology: Building the Scientific Foundation of India's Hydrogen Future

Long before green hydrogen emerged as a global strategic priority, the DST recognised hydrogen as an important clean energy carrier. For more than two decades, DST's Hydrogen and Fuel Cell Programme has nurtured research, innovation, and technology development across Indian universities,

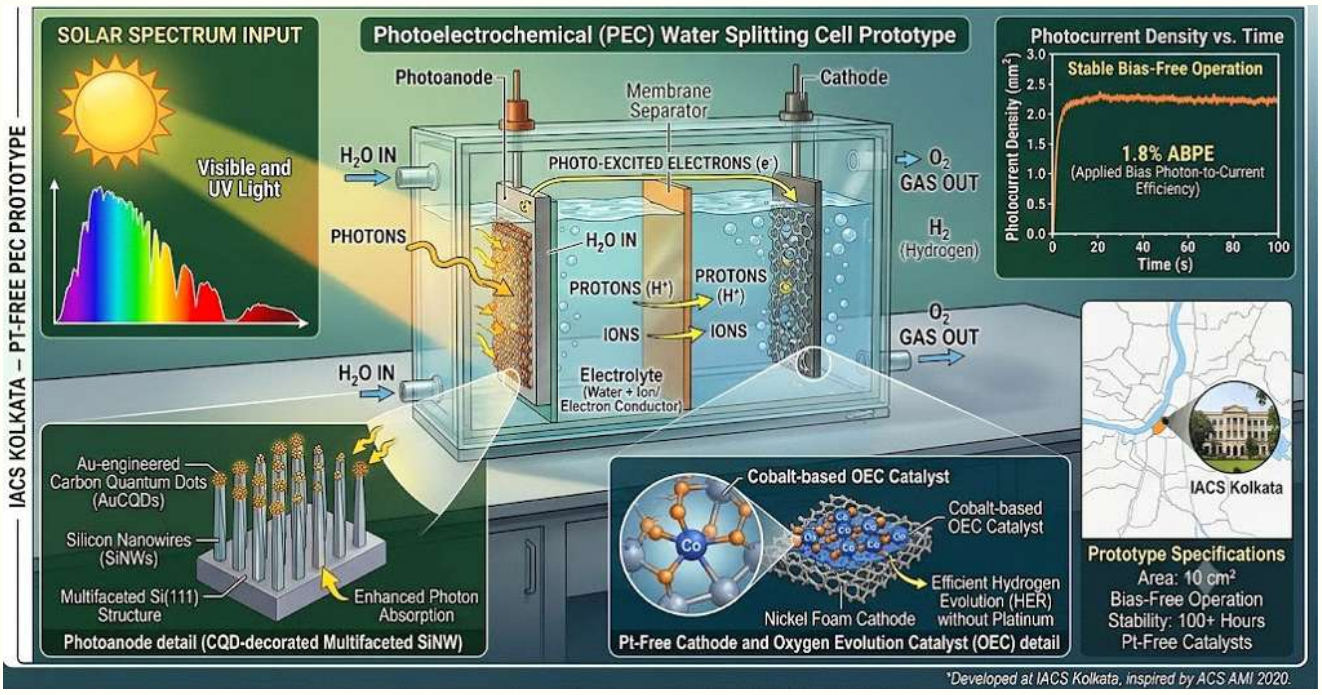
national laboratories, and research institutions. Today, many of these technologies are transitioning from laboratories toward pilot-scale demonstrations and commercialization.

DST-supported activities span the entire hydrogen value chain.

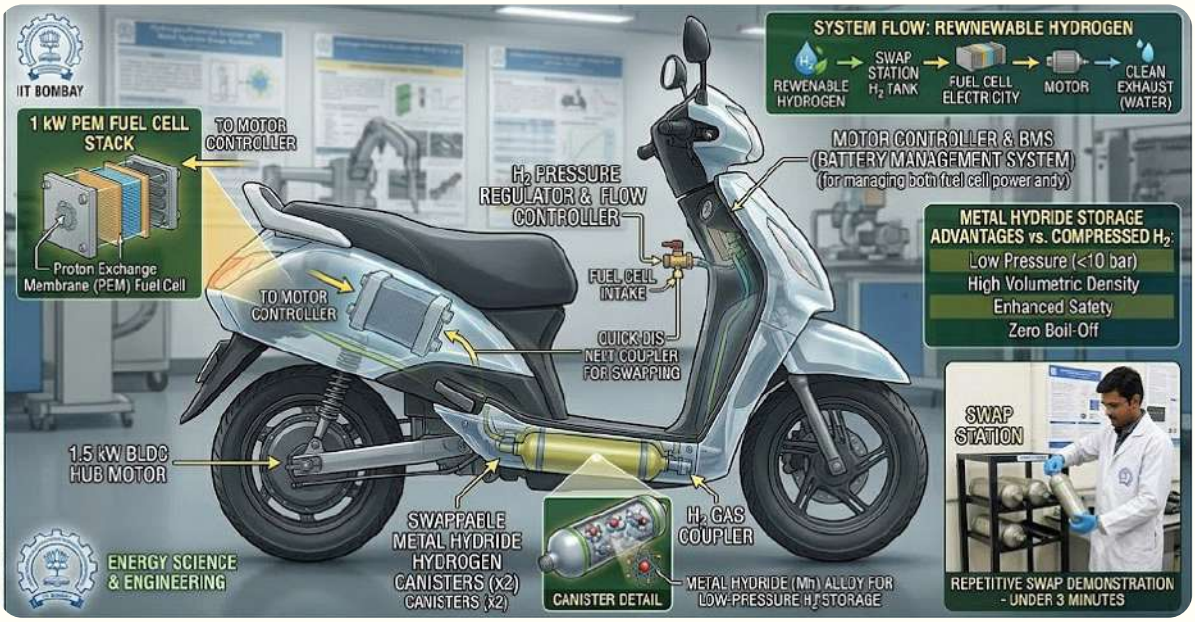
These include:

- **Advanced catalysts**
- **Electrolysers**
- **Photoelectrochemical hydrogen generation**
- **Fuel cells**
- **Metal hydride storage**
- **Purification technologies**
- **Compression systems**
- **Mobility applications**
- **Solar hydrogen**
- **Industrial demonstrations**

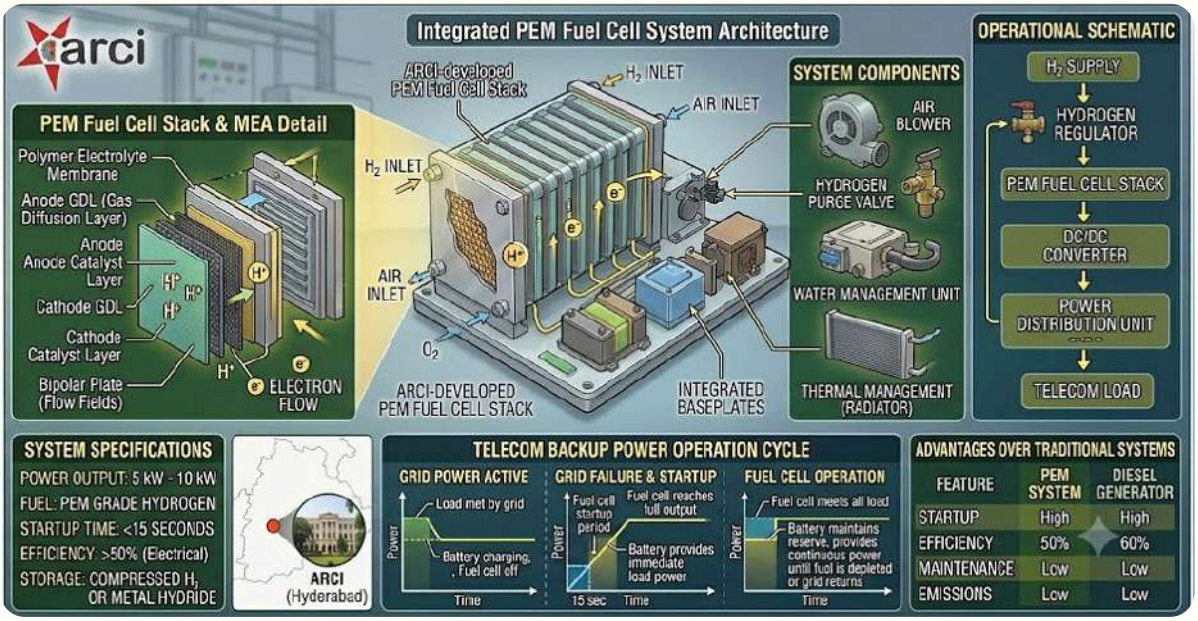
These efforts have significantly strengthened India's indigenous capabilities and contributed to the scientific foundation supporting the NGHM.



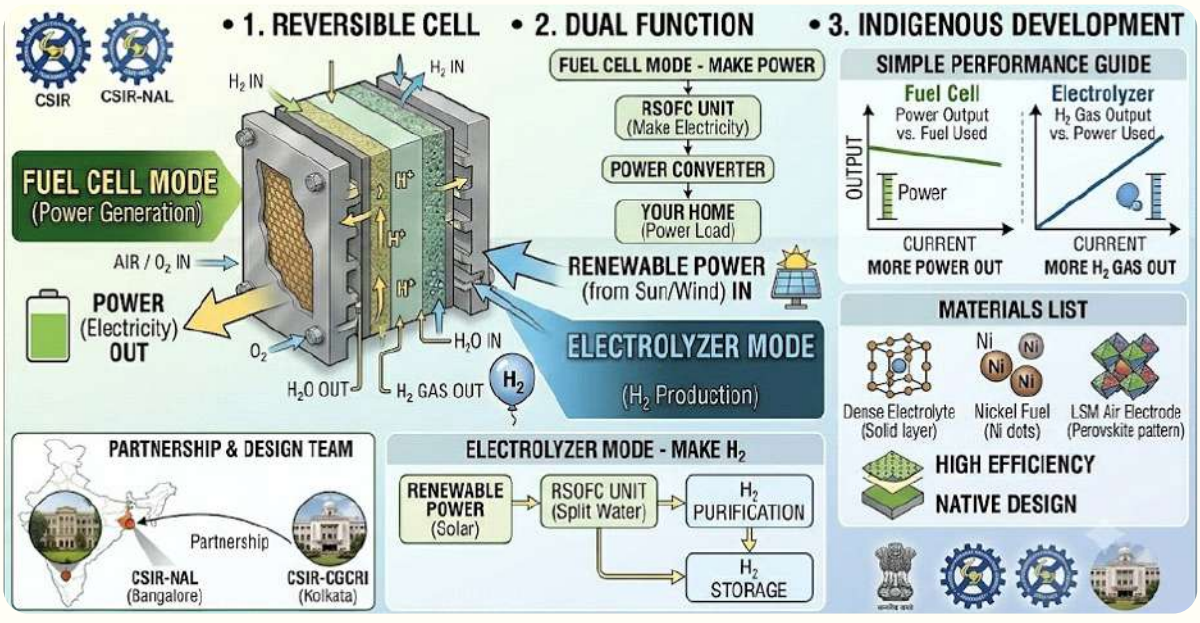
Pt-Free Photoelectrochemical Water Splitting Prototype Developed at IACS Kolkata



Hydrogen-Powered Scooter Integrated with a Metal Hydride Storage System Demonstrated at IIT Bombay



PEM Fuel Cell Telecom Backup Power System Developed by ARCI



Indigenous Reversible Solid Oxide Fuel Cell Developed by CSIR-NAL and CSIR-CGCRI

Certification, Societal Transformation and India's Hydrogen Roadmap to 2030

Building International Confidence: The Green Hydrogen Certification Scheme of India

As green hydrogen markets mature globally, transparency, traceability, and environmental integrity have become essential requirements for producers, investors, and international buyers. Recognizing this need, India launched the **Green Hydrogen Certification Scheme of India (GHCI)** in April 2025.

The GHCI establishes a robust Monitoring, Reporting, and Verification (MRV) framework to certify green hydrogen and its derivatives based on internationally accepted lifecycle assessment methodologies. The certification system is designed to provide a credible Guarantee of Origin for green hydrogen, ensuring that the product has been generated from renewable energy sources while meeting stringent emissions thresholds. India's certification framework stipulates that lifecycle greenhouse gas emissions should not exceed 2 kg CO_2 equivalent per kilogram of hydrogen produced, making it one of the most rigorous standards globally. Comparable international certification systems are being developed in the European Union, the United States, Japan, and Australia. By adopting stringent standards at an early stage, India is positioning itself to become a trusted supplier of green hydrogen, green ammonia, and green methanol in international markets.

The GHCI is expected to provide several benefits:

- **Facilitate access to global export markets;**
- **Enhance investor confidence;**
- **Enable participation in carbon trading mechanisms;**
- **Support compliance with Environmental, Social and Governance (ESG) requirements;**
- **Ensure transparency and minimize risks associated with greenwashing.**

The certification scheme therefore constitutes an important building block for establishing India's long-term competitiveness in the global green hydrogen economy.

Societal Benefits Beyond Decarbonisation

The NGHM extends far beyond climate mitigation. Its implementation is expected to generate widespread socio-economic benefits, contributing directly to India's aspirations of becoming a developed nation by 2047.

Energy Security

India imports a significant proportion of its crude oil, natural gas, and coal requirements. Green hydrogen offers a pathway to reduce this dependence by utilizing domestically available renewable energy resources. By replacing imported fossil fuels with indigenous green molecules, India can improve its trade balance and shield itself from geopolitical uncertainties and price volatility.

Industrial Competitiveness

Green hydrogen can help Indian industries remain competitive in an increasingly carbon-conscious global market. Emerging mechanisms such as the Carbon Border Adjustment Mechanism (CBAM) in Europe may impose additional costs on carbon-intensive products. Adoption of green hydrogen in steel, cement, refining, and chemical sectors can therefore enhance export competitiveness.

Employment Generation

The Mission is projected to create more than 600,000 direct and indirect jobs across manufacturing, project development, engineering, construction, operations, maintenance, logistics, and services. New employment opportunities are expected to emerge in electrolyser manufacturing, fuel-cell assembly, hydrogen infrastructure development, testing laboratories, certification agencies, and startup ecosystems.

Regional Development

Hydrogen Valleys and associated industrial clusters are likely to stimulate economic activities in several regions of the country. Investments in production facilities, storage infrastructure, transportation networks, and end-use applications can foster balanced regional development and attract private sector participation.

Innovation and Entrepreneurship

The hydrogen economy offers fertile ground for startups and innovation-driven enterprises. Opportunities exist in advanced materials, catalysts, membranes, digital twins, safety systems, hydrogen sensors, AI-enabled process optimization, and decentralized hydrogen solutions. The Mission therefore has the potential to nurture a vibrant innovation ecosystem aligned with India's startup ambitions.

Rural Applications

Hydrogen technologies may also support decentralized energy systems, agricultural applications, telecom backup power, and resilient energy solutions for remote communities. In the long term, hydrogen could complement renewable energy systems to provide reliable and clean power for rural development.

Looking Towards 2030 and Beyond

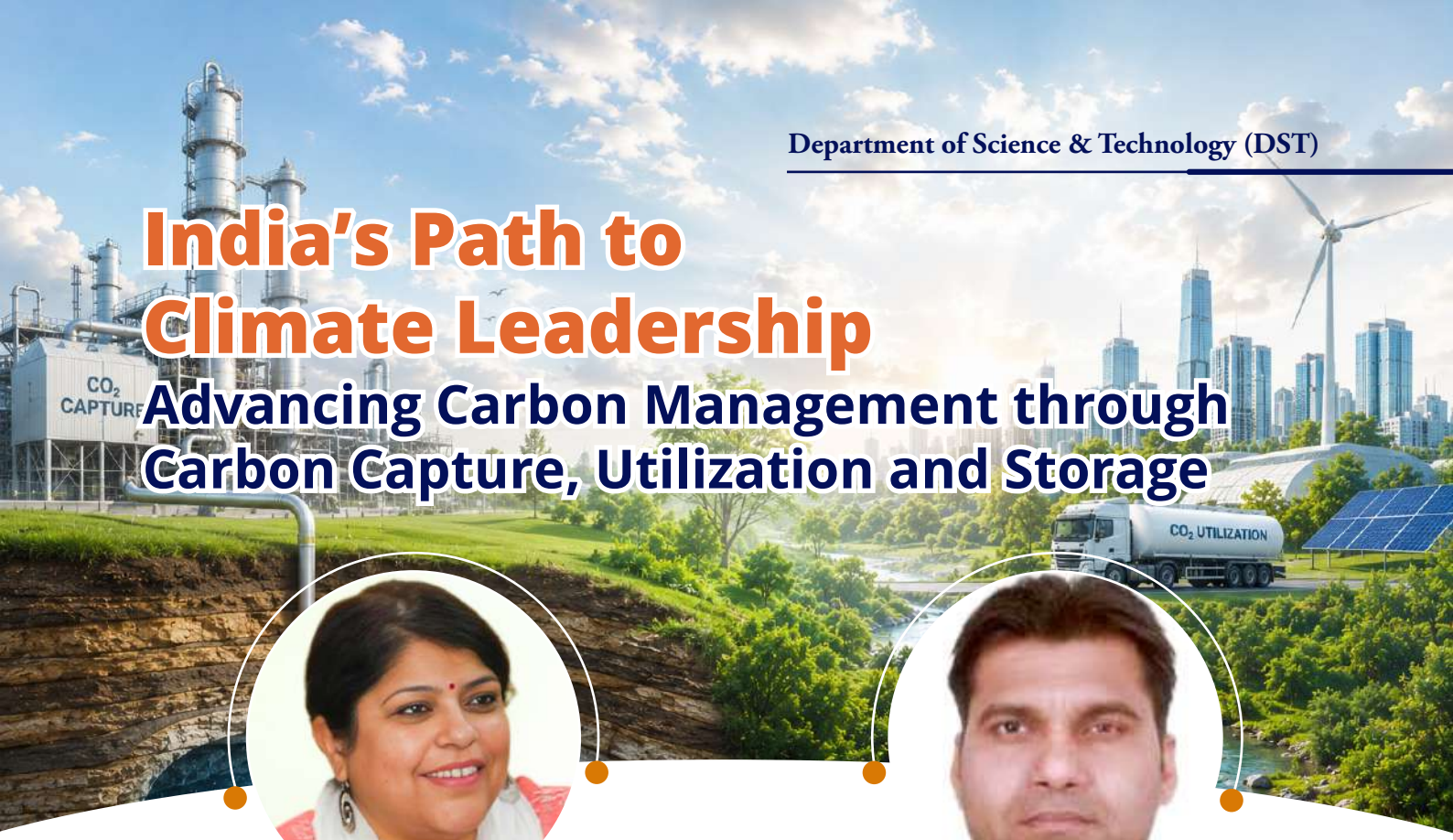
India's hydrogen journey has moved decisively from vision to implementation. Electrolyser gigafactories are under construction, long-term green ammonia agreements are being executed, hydrogen buses and trucks are being demonstrated, and Hydrogen Valley Innovation Clusters are beginning to take shape. At the same time, scientific institutions continue to push technological frontiers. Research efforts supported by the Department of Science and Technology are advancing photoelectrochemical hydrogen generation, reversible solid oxide cells, metal hydride systems, advanced electrocatalysts, and next-generation fuel cells. These innovations will be essential for reducing costs, improving efficiencies, and enhancing the long-term sustainability of hydrogen systems. Challenges undoubtedly remain. The cost of green hydrogen must continue to decline. Infrastructure for storage and transportation needs to be developed. Water availability, supply chains, and safety regulations require sustained attention. Nevertheless, India's scientific capabilities, industrial base, policy framework, and renewable energy potential provide a strong foundation for overcoming these challenges.

The NGHM therefore represents far more than a clean energy programme. It symbolizes India's determination to lead the next wave of industrial transformation. By combining visionary policymaking, scientific excellence, technological innovation, and collaborative partnerships, the Mission offers a compelling example of how a developing economy can simultaneously pursue climate ambition, energy security, and economic prosperity.

The National Green Hydrogen Mission demonstrates how science, innovation, industry, and policy can converge to shape a cleaner, more resilient, and prosperous future. As India marches towards Viksit Bharat 2047, green hydrogen is poised to become one of the defining pillars of the country's next green industrial revolution.

India's Path to Climate Leadership

Advancing Carbon Management through Carbon Capture, Utilization and Storage



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As the world confronts escalating temperatures, extreme weather events, and environmental degradation, the urgency for decisive climate action has never been greater. Nations across the globe are under increasing pressure to balance economic growth with environmental responsibility. In this context, India has emerged as a proactive leader, demonstrating a strong commitment to climate mitigation while pursuing sustainable development.

India's climate ambition is anchored in its long-term vision of achieving net-zero emissions by 2070. The "Panchamrit" commitments reinforce this vision announced at COP-26, which outline a comprehensive pathway to reduce emissions, scale up renewable energy, and foster climate resilience. Department of Science and Technology ,Government of India, pioneered an initiative on **Carbon Capture, Utilization and Storage (CCUS)** in 2018 to promote research, innovation, technology development, tech assessment to accelerate CCUS technologies, build the national capacity and to support India's long-term net-zero emission goals.

Central to this transformative journey initiated by DST is the strategic adoption of Carbon Capture, Utilization, and Storage (CCUS) technologies as an approach that addresses emissions from hard to abate sectors like Power, Steel and Cement that are otherwise difficult to decarbonize.

Department of Science and Technology (DST), has been instrumental in this effort, driving forward the country's CCUS agenda through innovative research, technological development, and strategic partnerships. With a clear focus on fostering collaboration, capacity-building, and technological innovation, DST is laying the groundwork for a carbon-neutral future. By championing CCUS technologies, DST is not only contributing to India's climate goals but also reinforcing India's position as a leader in the global climate action movement.

The Imperative for Carbon Management

CCUS is emerging as a critical technology for achieving India's net-zero ambitions by addressing emissions from sectors where decarbonization remains particularly challenging. Heavy industries such as power generation, cement, steel, and other energy-intensive sectors often referred to as "hard-to-abate" industries, continue to rely on fossil fuels and involve process-related emissions that cannot be eliminated through energy efficiency or fuel switching alone.

In this context, CCUS technologies provides a practical and scalable solution to this challenge. By capturing carbon dioxide emissions at their source, and either storing them underground or converting them into value-added products, CCUS enables relevant industries to reduce their environmental impact without compromising productivity. This dual benefit makes CCUS indispensable as part of the concerted effort for achieving long-term climate goals.

Moreover, CCUS aligns with India's broader commitment to climate justice. As a developing economy, India must ensure that its industrial growth does not come at the expense of environmental sustainability. CCUS offers a pathway that supports economic expansion while minimizing ecological damage, ensuring a balanced and equitable transition to a low-carbon future.

DST's Leadership in Driving CCUS Innovation and Management

At the forefront of India's Carbon Capture, Utilization and Storage (CCUS) initiatives, DST has initiated a comprehensive programme encompassing fundamental and applied research, pilot-scale test beds for technology validation, and translational innovation. Innovative models has been devised throughcompetitive funding mechanisms, interdisciplinary research initiatives, industry–academia partnerships, and international collaborations. DST has promoted the advancement of indigenous carbon capture, CO_2 utilization pathways and geological storage assessment, carbon mineralization, and carbon-to-value technologies through its vast efforts.

Facility for CO2 to methanol conversion at JNCASR, Bengaluru

These initiatives have strengthened India's scientific and technological capabilities in CCUS research and management, facilitated technology readiness for industrial deployment, and established a collaborative innovation ecosystem that supports the development of scalable, cost-effective, and sustainable CCUS solutions for industrial decarbonization.

One of the defining features of DST's approach is its emphasis on end-to-end innovation. From fundamental research on advanced materials to pilot-scale demonstrations, DST has ensured that CCUS technologies are developed across the entire value chain.

The establishment of National Centres of Excellence (NCoEs) has further strengthened India's capabilities in CCUS. These centres, located at leading institutions such as Jawaharlal Nehru Centre for Advanced Scientific Research (JNCASR) Bengaluru, Indian Institute of Technology (IIT) Bombay and CSIR–National Environmental Engineering Research Institute (NEERI) Nagpur, are driving breakthroughs in the domain of Carbon Capture, CO_2 conversion, and storage technologies. Their collaborative efforts are bridging the gap between laboratory research and real-world applications. These centres envisage to facilitate the mapping of current R&D and innovation activities in the domain of CCUS and develop networks of researchers, industries and stakeholders by fostering the synergized research between partnering groups and organizations. The centres are acting as nucleating sites for promoting multi-disciplinary, collaborative and capacity-building hubs for state-of-the art research and application-oriented initiatives in the field of CCUS.

Breakthrough Innovations and Achievements

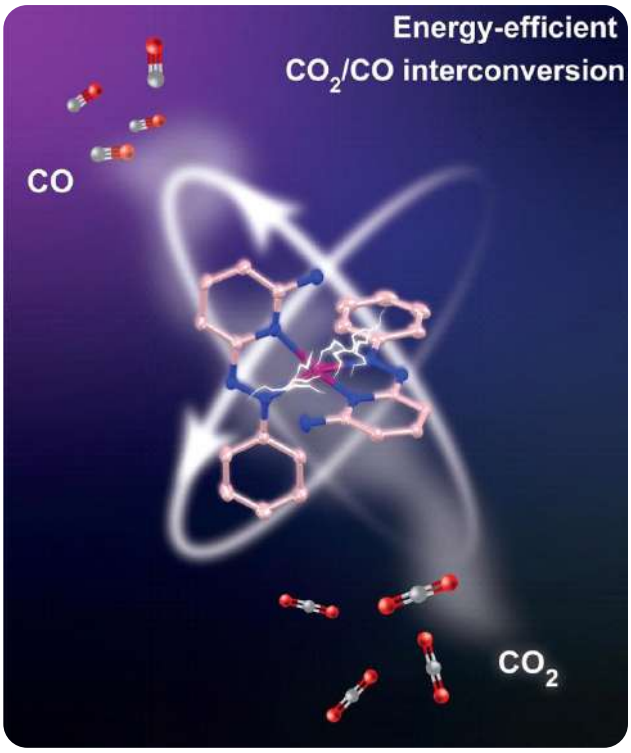
India's progress in CCUS is marked by several notable achievements supported by DST interventions. These innovations demonstrate not only technological advancement but also strong potential for commercialization and large-scale deployment.

The National Centre of Excellence (NCoE) for Carbon Capture and Utilization at JNCASR Bengaluru has pioneered multiple pathways for converting CO_2 into useful chemicals and fuels, including methanol,

dimethyl ether, ethanol, and syngas. Complementing these efforts, the co-founded start-up Breathe Applied Sciences has played a key role in translating these innovations to deployment. These innovations are not only reducing emissions but also contributing to energy security and industrial sustainability by enabling the production of green fuels and chemicals. As part of the NCoE-JNCASR activities, a facility has been also established at 280 kg/day capacity for CO2 to methanol conversion from the NCoE activities. A start up Breathe India Ltd has also emerged from the activities of the NCoE -JNCASR Bengaluru.

Similarly, another significant development is the indigenous aqua-based carbon capture technology developed at IIT Bombay. Designed with a focus on micro, small, and medium enterprises (MSMEs), this technology captures CO_2 from industrial emissions and converts it into value-added products such as carbonates and speciality chemicals. Its successful licensing to a startup highlights its readiness for market adoption. Given its alignment with national priorities on climate action and circular economy, the aqua-based CCU platform licensed to a startup 'UrjanovaC Pvt Ltd', demonstrates strong potential for near-term commercialization.

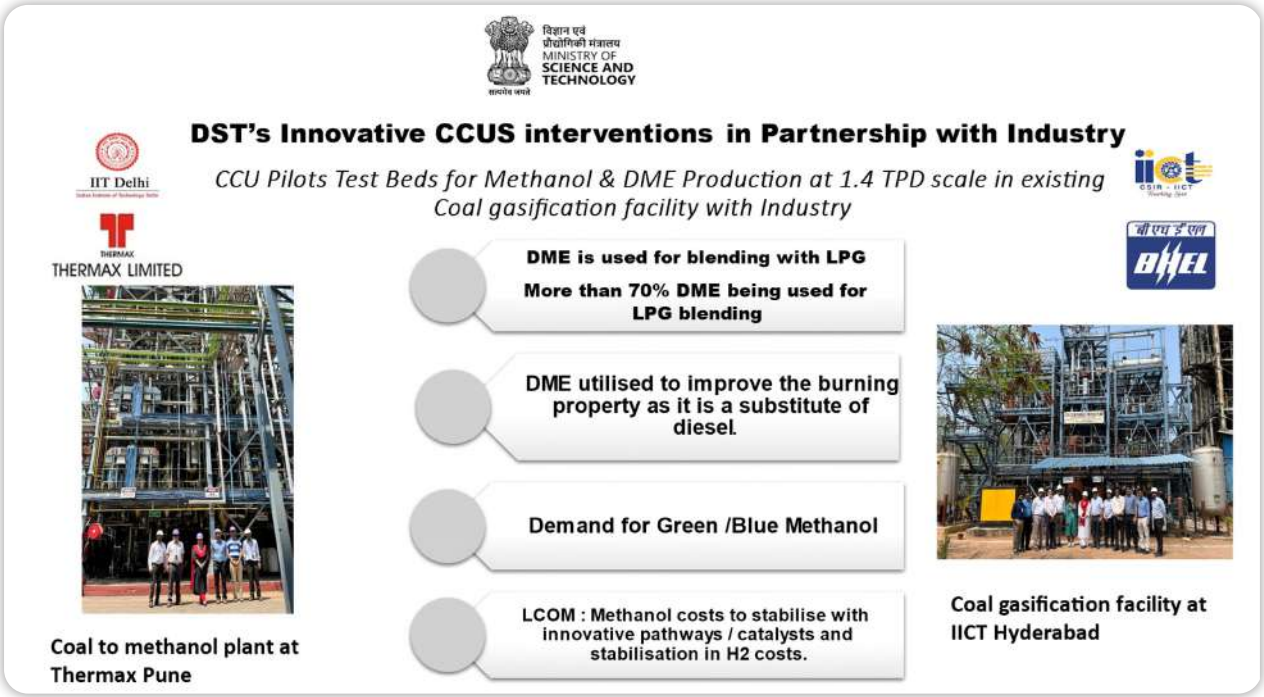
DST has also devised innovative funding mechanisms in Public-Private Partnerships (PPP) mode to establish CCU testbeds in the thermal power sector. Collaborative projects involving institutions such as IIT Delhi, CSIR-IICT Hyderabad, and industry partners like BHEL and Thermax has been established for validating the feasibility of converting captured CO_2 into green fuels such as dimethylether and methanol within coal gasification systems. These initiatives are particularly significant for reducing emissions in thermal power plants, one of the largest contributors to India's carbon footprint.



Energy-efficient CO2/CO interconversion

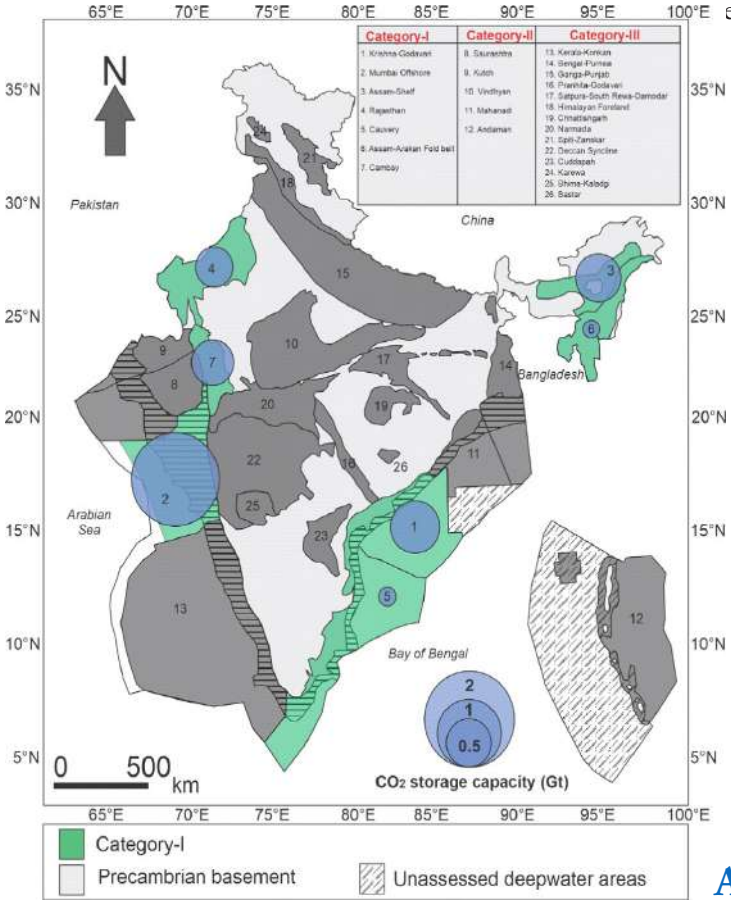
Advancing Carbon Storage Technologies

In addition to Capture and Utilization, India is making substantial progress in carbon storage solutions. Research supported by DST has led to development of methodologies for estimating CO_2 storage capacity

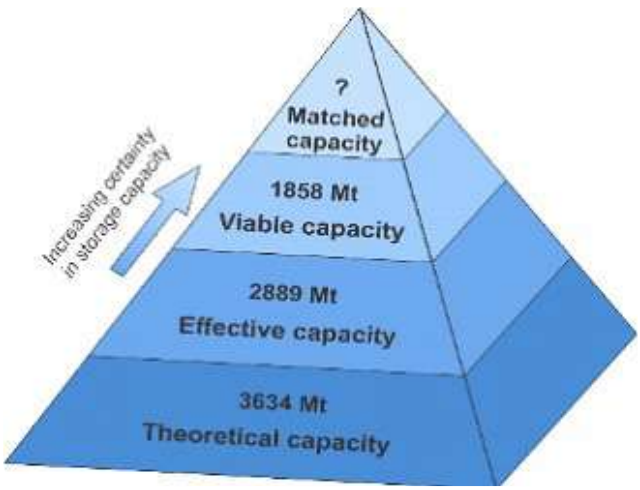


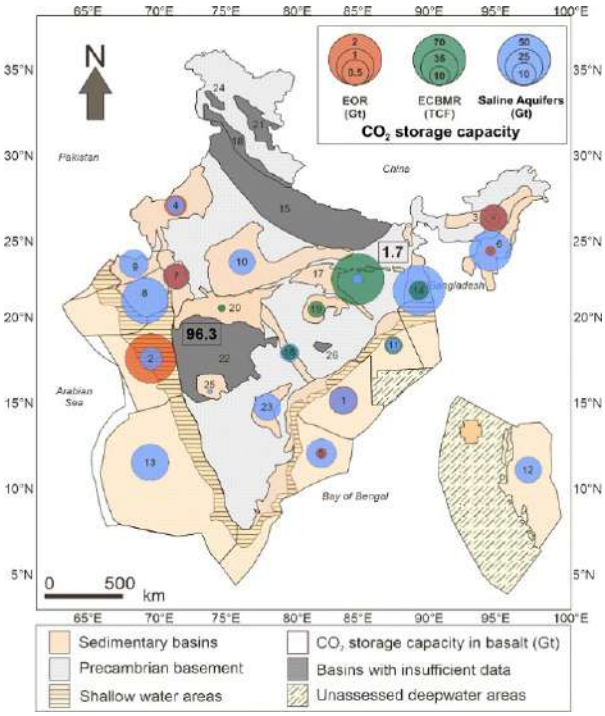
across various geological formations, including saline aquifers, basalt deposits, and enhanced oil recovery sites.

A significant contribution to India's Carbon Capture and Storage (CCS) programme has been made through a study led by IIT Bombay on the assessment of the country's geological CO_2 storage potential. The study systematically evaluated prospective sedimentary basins, depleted oil and gas reservoirs, deep saline aquifers, and coal-bearing formations to identify suitable geological formations for the safe and permanent storage of captured CO_2. Using geological, geophysical, and reservoir characterization approaches, the study estimated the storage capacities of key basins and assessed critical parameters such as injectivity, containment integrity, reservoir suitability, and long-term storage security. The findings provide a scientific foundation for identifying priority CO_2 storage sites and support the development of a national geological storage atlas, thereby facilitating the large-scale deployment of CCUS technologies for industrial decarbonization in India.



CO2 storage potential of different sedimentary basins in India





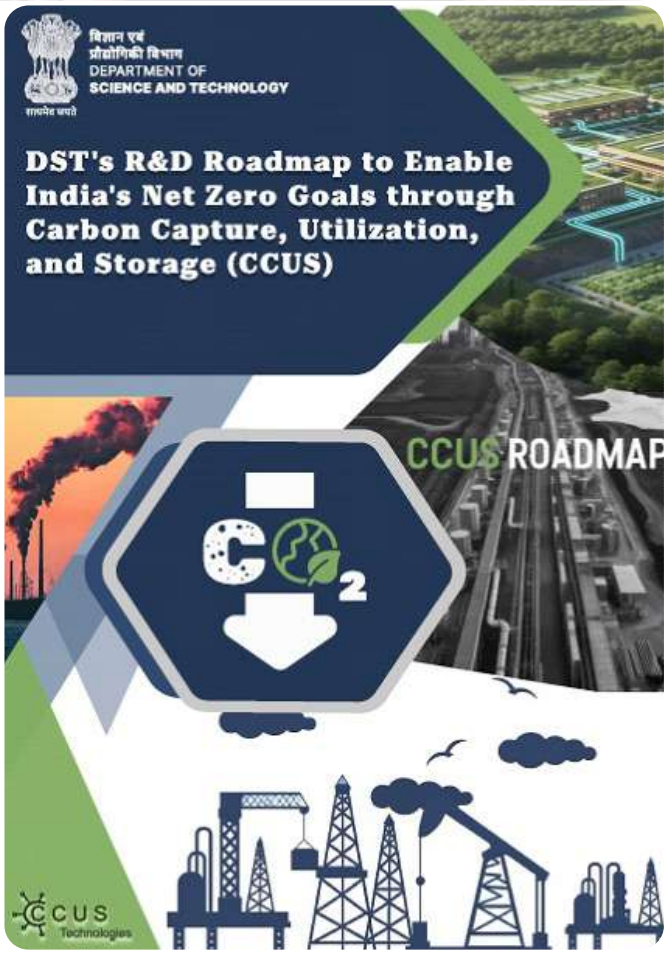
A Strategic Roadmap for CCUS Deployment

Recognizing the complexity of implementing CCUS at scale, DST has developed a comprehensive first of its kind Roadmap for CCUS R&D to guide research, innovation, and deployment efforts. This roadmap emphasizes the need for cost-effective technologies, scalable solutions, and strong policy frameworks.

Central to this vision is the High Task Force established by DST, which brought together experts from various sectors, including academia, industry, policy-makers , government and funding agencies, to ensure that efforts to advance CCUS are aligned with India's climate goals. The roadmap underscores the importance of capacity building and skill development. Through workshops, training programs, and international collaborations, DST is equipping India's workforce with the expertise needed to lead the

transition to a low-carbon economy. The roadmap addresses critical techno-economic, regulatory, and infrastructure-related barriers to CCUS deployment, including high capital expenditure, operational costs, and the need for dedicated CO_2 transport and storage infrastructure. It recommends the implementation of supportive policy and regulatory frameworks, carbon pricing mechanisms, market-based incentives, and targeted financial support to create an enabling R & D environment as well as large-scale deployment and commercialization of CCUS technologies in India.

In alignment with the recommendations of the DST's CCUS R&D Roadmap, the National Mission on CCUS was announced by the Hon'ble



R&D Roadmap launched to enable India's Net Zero Targets through CCUS

Finance Minister in Parliament on 1st February 2026 as part of the Union Budget 2026–27, with an overall outlay of ₹20,000 crore for a period of six years. The Mission is expected to catalyse the development of indigenous CCUS technologies, strengthen the national carbon management ecosystem, and accelerate the decarbonization of India's hard-to-abate industrial sectors.

Strengthening Global Collaboration

India's commitment to CCUS extends beyond national boundaries. Through participation in international initiatives such as the Accelerating CCUS Technologies (ACT) program and the Clean Energy Transition Partnership (CETP), DST India is actively collaborating with global partners to address technical and economic challenges.

These collaborations enable Indian researchers to access cutting-edge technologies, share best practices, and contribute to global climate solutions. Joint projects focusing on areas like CO_2 sequestration, advanced materials, and subsurface analysis are enhancing India's capabilities while fostering innovation on a global scale.

Such partnerships are essential for addressing the interconnected nature of climate change and ensuring that solutions are both inclusive and effective.

Economic and Environmental Synergies

One of the most compelling aspects of CCUS is its ability to create economic value while reducing emissions. By converting captured CO_2 into fuels, chemicals, and construction materials, CCUS opens up new industrial opportunities and supports the development of a circular carbon economy.

For India, this translates into reduced dependence on imports, particularly in sectors like energy and chemicals, while strengthening domestic manufacturing capabilities. Initiatives aligned with national missions such as Atmanirbhar Bharat further highlight the strategic importance of CCUS in achieving technological self-reliance.

At the same time, CCUS contributes to environmental sustainability by significantly lowering greenhouse gas emissions. This dual impact reinforces its role as a cornerstone of India's climate strategy.

Challenges and the Way Forward

Despite its transformative potential, the large-scale adoption of CCUS technologies is constrained by several techno-economic, infrastructural, and regulatory challenges. These include high capital investment and operating costs, lack of measurement and monitoring mechanisms, the need for integrated CO_2 transportation and geological storage infrastructure, and the development of robust policy, regulatory, and market mechanisms to support commercial-scale deployment.

Addressing these challenges requires sustained investment, policy support, and continued innovation. DST's integrated approach combining research, funding, and collaboration is well-positioned to overcome these obstacles and accelerate the deployment of CCUS technologies.

Looking ahead, the success of CCUS will depend on strong partnerships between government, industry, and academia, as well as active participation in global climate initiatives.

A Call to Action

India's approach to climate action demonstrates that sustained economic growth and industrial development can be effectively aligned with long-term decarbonization objectives through strategic investments in science, technology, and innovation. India's journey in climate action demonstrates that it is possible to pursue economic growth while prioritizing environmental sustainability.

Through its leadership in CCUS, supported by the pioneering and visionary efforts of the DST , India is charting its path towards a low-carbon future. The integration of innovation, policy, and collaboration is enabling the country to address one of the most pressing challenges of our time.

The message is clear: combating climate change requires collective action, sustained commitment, and transformative solutions. CCUS represents not just a technological advancement, but a strategic opportunity to redefine the relationship between industry and the environment through critical JEST (Just Sustainable Energy Transitions) approach India's CCUS journey offers valuable lessons for the world, showing that with the right vision and determination, a sustainable and resilient future is within reach

Advancing Technology Development, Accelerating Commercialisation

Celebrating 30 Years of the Technology Development Board

Dr Kapil Kumar Tripathi

Scientist F
Technology Development Board
Government of India

A nation's true strength lies not only in its economic growth but also in its ability to transform indigenous knowledge and innovation into globally competitive technologies. Converting research into commercially viable products and scalable enterprises is fundamental to achieving technological self-reliance, strengthening industrial competitiveness, and driving sustainable economic development. Realising this vision requires sustained support for innovation across the entire technology lifecycle, from research and product development to commercialisation and market adoption, empowering Indian enterprises to build world-class technologies that address national priorities and compete successfully on the global stage.

With this objective, the Technology Development Board (TDB) was established in September 1996 as a statutory body under the Department of Science and Technology, Government of India. Over the past thirty years, TDB has played a pioneering role in bridging the gap between laboratory research and the marketplace by providing financial assistance to industry for the development and commercialization of indigenous technologies. It has also facilitated the successful absorption and adaptation of imported technologies to meet national priorities and enhance India's technological capabilities. Through its unwavering commitment to fostering innovation, strengthening industrial competitiveness, and accelerating technology commercialization, TDB has emerged as a key catalyst in building an innovation driven, self-reliant, and globally competitive India.

The Technology Development Board has long benefited from the guidance of renowned scientists, technologists, and industrialists, which has provided vision and direction in addressing the needs of Indian industry. Prof. V. S. Ramamurthy was the first Chairman of the Board, and the Missile Man of India and Bharat Ratna awardee, the late Dr A. P. J. Abdul Kalam, was among its first members. Several distinguished leaders from Indian industry have also served as members of the Board, including Subodh Bhargava, Dr Kiran Mazumdar-Shaw, and Dr Cyrus S. Poonawalla.

The year 1997–98 marked the beginning of the Technology Development Board's journey from vision to action. In its very first year of operations, TDB signed nearly 20 agreements, extending financial assistance of about Rs 20.00 crore to support the commercialization of promising technologies. What began as a modest initiative has, over the past three decades, evolved into one of India's foremost technology financing mechanisms, driving innovation led industrial growth across diverse sectors.

Today, TDB's expanding footprint reflects the growing confidence of India's innovation ecosystem in its mission and approach. The Board has approved and supported 444 projects for startups, MSMEs, and big companies with financial assistance of nearly Rs 3261.60 crore (Total Project Cost Rs 13179.83 crore). These investments have catalysed the commercialisation of cutting-edge technologies, strengthened indigenous technological capabilities, nurtured technology-based entrepreneurship, and accelerated the transformation of innovative ideas into globally competitive products and enterprises. Through these sustained efforts, TDB has emerged as one of India's pioneering institutions for promoting the development and commercialisation of indigenous technologies. Its mandate includes:

- **Providing financial assistance to industrial enterprises and other agencies for the commercial application of indigenous technologies and adaptation of imported technologies.**
- **Supporting recognised R&D institutions in developing indigenous technologies and adapting imported technologies for large-scale application.**
- **Undertaking additional functions as assigned by the Government of India from time to time.**

TDB extends financial support in the form of Loans, Equity and Grants (in exceptional cases). In accordance with its mandate, TDB provides financial assistance of up to 50% of the total project cost to companies for the commercialisation of indigenous technologies. This support has empowered numerous small enterprises, including startups, to evolve into globally competitive multinational companies and unicorns, earning international recognition. The programmes and activities of TDB are as follows;

TDB- Core Scheme

Under the TDB Core Scheme, the Technology Development Board (TDB) provides financial assistance to startups (registered with DPIIT), MSMEs, and corporate/ big enterprises (registered under the Companies Act) for the development, scaling, and commercialisation of indigenous technologies, preferably at Technology Readiness Level (TRL) 6 and above. The financial assistance is provided in the form of soft loans carrying a simple interest rate of 5% per annum, or as equity support through upfront equity investment of up to 25% or Optionally Convertible Debt (OCD) of up to 25%, which may be converted into equity at a later stage based on the company's valuation. This flexible financing framework enables innovators and enterprises to bridge the gap between technology development and successful commercialisation, while supporting the growth of technology-driven ventures across different stages of their lifecycle. Under this scheme, TDB extends financial support to projects across a wide range of strategic and high-impact sectors, including Healthcare and Medical Technologies; Energy and Waste Utilization; Defence and Civil Aviation; Electronics and Semiconductor Technologies; Space Technologies; Agriculture; Engineering and Advanced Manufacturing; Telecommunications and Digital Technologies; Chemicals and Process Industries; Road Transport and Mobility; and others. Interested startups, MSMEs, and large industries may submit project proposals to TDB throughout the year under its regular funding schemes. In addition, TDB periodically launches thematic calls for proposals in strategic and emerging technology areas, aligned with national priorities and evolving technological needs.

TDB-SLFM Under RDI Scheme

The Research, Development and Innovation (RDI) Scheme is a flagship initiative of the Department of Science & Technology (DST), Government of India, launched by the Hon'ble Prime Minister in November 2025. With a total outlay of Rs 1.00 lakh crore over six years, the scheme aims to catalyse private sector investment in research, development, and innovation, strengthen India's innovation ecosystem, and accelerate the commercialization of indigenous technologies. Under this scheme, financial assistance is provided to private sector enterprises, startups, MSMEs, and industries operating in sunrise and strategic sectors to support the entire innovation lifecycle—from research

and development to the commercialisation of indigenous technologies. Technology Development Board (TDB) is serving as a second-level fund manager (SLFM) under this Scheme. The scheme is open for Eligible Technology Entities (ETE's) who are engaged in developing and scaling RDI-intensive technologies & products in RDIF priority and sunrise sectors. These priority and sunrise sectors are Energy security, transition and climate action; Deep Technology, including Quantum computing, Robotics, and Space; Artificial Intelligence and its application to Indian problems, including Agriculture, Health, and Education; Biotechnology, pharmaceuticals and medical devices; Digital economy, including digital agriculture. Eligible Technology Entities (ETE's) whose technology is TRL 4 and above are eligible to apply. The proposal can be submitted online throughout the year. The key features of the scheme include:

- **Collateral-free financing to facilitate easier access to funding for technology-driven enterprises.**
- **Financial assistance of up to 50% of the total project funding requirement, with the balance contributed by the company and/or private investors.**
- **Soft loans carrying a nominal/simple interest rate of 3%(in case of OCD) or 4% (in case of a loan) per annum.**
- **Flexible repayment tenure of up to 10-15 years, including an appropriate moratorium period, depending on the nature and stage of the project.**
- **Equity participation of up to 25% of the approved TDB assistance, with the remaining assistance provided as a soft loan. TDB's equity holding is, however, capped at 25% of the company's total shareholding.**

TDB launched the first open call under the Research, Development and Innovation (RDI) Scheme in February 2026, which received an overwhelming response from startups and technology-driven enterprises across the country. As of 30 April 2026, 22 Emerging Technology Enterprises (ETEs) had been selected for financial assistance.

The selected Startups/Companies represent a diverse range of strategic technology sectors, including Deep Technologies (Quantum Technologies, Robotics, and Space) (13 Projects), Biotechnology and Medical Devices (4 Projects), Energy Security and Climate Change (3 Projects), Artificial Intelligence and its Applications (1Project), and the Digital Economy, including Digital Agriculture (1Projet). These projects are expected to accelerate technology development, commercialization, and innovation-led economic growth in the country.

TDB- International Programme

With the support of the Department of Science and Technology (DST), Government of India, Technology Development Board (TDB) has been actively promoting international technology partnerships by supporting collaborative research, development, and commercialization projects between

First Call Launch under RDI by TDB as a Second Level Fund Manager

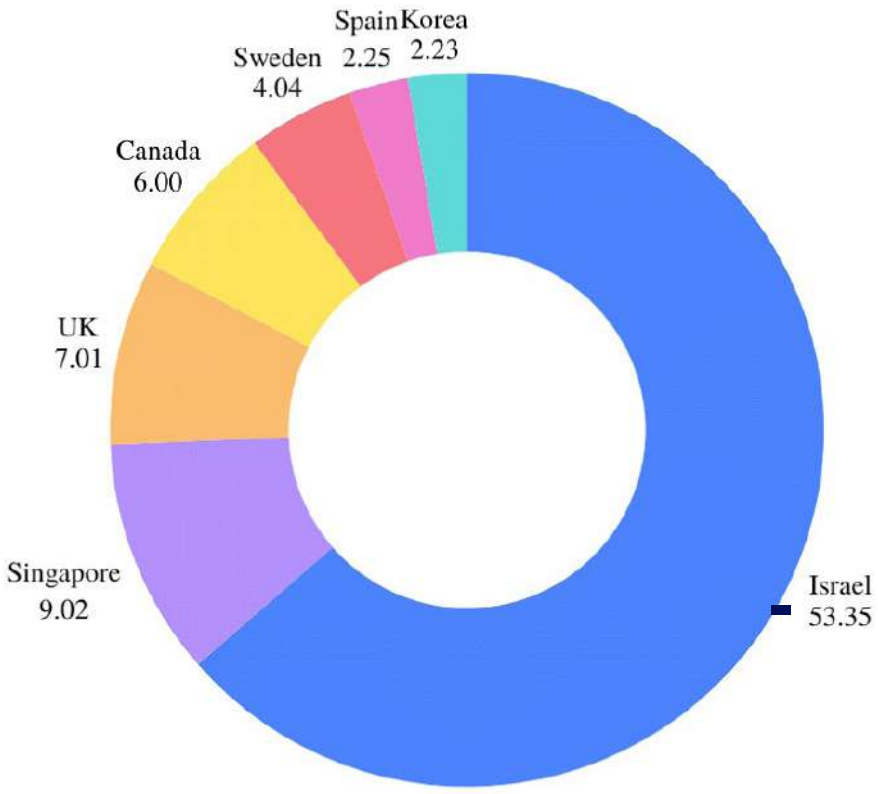
Indian companies and their counterparts abroad. To foster cross-border innovation and accelerate technology commercialization, TDB has launched various bilateral Calls for Proposals in association with the Department of Science and Technology for Canada, Finland, Israel, Singapore, Spain, Sweden, and the United Kingdom.

Over the years, TDB has built a strong international collaboration portfolio, supporting 34 joint technology projects across seven partner countries, with a total financial assistance of Rs 83.90 crore. Among all partner nations, Israel has emerged as TDB's largest international collaboration partner, receiving financial assistance of Rs 53.35 crore.

The programme has supported technologies in several strategic sectors, including Healthcare and Medical Technologies, Aerospace, Information Technology and Artificial Intelligence (AI), Energy and Sustainability, and Defence Technologies, thereby strengthening India's global innovation ecosystem and promoting the development and commercialization of cutting-edge technologies through international cooperation.

TDB's Global Presence

Strengthening International Collaboration in Industrial Research and Development



TDB's Journey of Innovation, Impact, and Success

Among the projects supported by TDB are several that were initially regarded as high-risk but later became landmark achievements in India's technological journey. These include the development and commercial production of India's first indigenous vaccines (Hepatitis-B), the country's first electric car, REVA, and the development of the Tata Indica, India's first indigenously developed passenger car. These success stories demonstrate TDB's commitment to supporting transformative technologies that contribute to the vision of Atmanirbhar Bharat.

TDB has played a catalytic role in strengthening India's pharmaceutical and biotechnology sector by supporting the commercialisation of indigenous technologies.

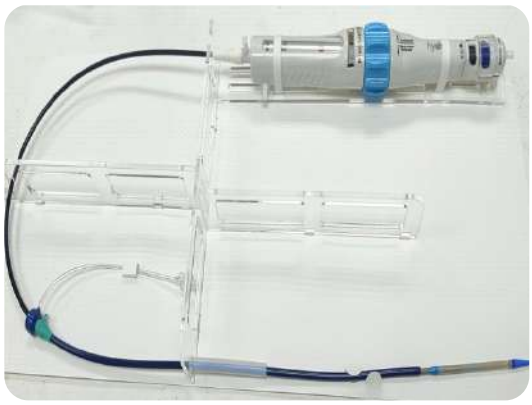
Many of India's leading pharmaceutical and biotechnology companies have benefited from TDB's assistance in developing new drug molecules, vaccines, medical devices, and other innovative healthcare solutions. Among the notable beneficiaries is Kiran Mazumdar-Shaw, whose company received early support from TDB for the commercialisation of indigenous biotechnology innovations. She has acknowledged that TDB's timely financial assistance played an important role in helping the company translate research into commercially successful products, contributing to its emergence as one of India's leading global biopharmaceutical companies.

The success of companies such as Biocon, led by Kiran Mazumdar-Shaw, shows how TDB helps can transform research-driven enterprises into globally competitive companies, creating high-value employment, promoting exports, and enhancing India's technological self-reliance. Reflecting on the partnership with TDB, Dr Krishna Ella, Chairman and Managing Director of Bharat Biotech, said, "TDB's support for our first Hepatitis B vaccine project was instrumental in our journey. Over the past three decades, this partnership has helped us grow into a global leader in vaccines, with several hundred million doses supplied in India and around the world." TDB, with this breakthrough, reduced the price of the vaccine drastically, making life-saving immunisation affordable and accessible to millions of people in India and other developing countries while demonstrating the transformative impact of indigenous innovation.

TDB's support has enabled the development of several breakthrough medical technologies that are transforming healthcare in India and beyond. M/s Panacea Medical Technologies developed an indigenous Medical Linear Accelerator (LINAC), incorporating critical components such as the LINAC tube and magnetron. This landmark innovation has significantly reduced the cost of advanced radiotherapy systems, making high-quality cancer treatment more affordable and accessible. The company's next-generation system, Siddharth II, is now ready for global commercial deployment, has secured three international patents, and has generated strong interest from the European Union and the United Kingdom, while countries such as Hungary, Serbia, Romania, and Croatia are in advanced stages of discussions for clinical deployment.

Similarly, M/s Sahajanand Medical Technologies developed an indigenous Transcatheter Aortic Valve Implantation (TAVI) system, a minimally invasive technology for the treatment of aortic valve stenosis that reduces the need for open-heart surgery, improving

Siddharth II: Advanced Medical LINAC for Cancer Therapy



(Indigenous Transcatheter Aortic Valve Implantation (TAVI)

Hepatitis-B Vaccine “Revac

Indigenous advanced ICU ventilator

patient safety and recovery. M/s Noccarc developed an indigenous advanced ICU ventilator, providing hospitals with a high-quality, digitally enabled, and affordable critical care solution. These innovations not only improve healthcare outcomes but also position India as a global hub for affordable, world-class medical innovation.

In the field of drone technology, M/s BotLab Dynamics developed India's first large-scale indigenous drone swarm system under the project "Design and Development of a Reconfigurable Swarming System Consisting of 500–1000 Drones for 3D Choreographed Drone Light Shows." The breakthrough has established the company as one of the country's leading deep-tech startups, delivering spectacular aerial displays at major national and international events.

In the space sector, M/s Agnikul Cosmos Private Limited is developing and commercialising a Modular Configurable Launch Vehicle capable of placing payloads of up to 300 kg into orbit. The project showcases the growing capabilities of Indian startups in providing affordable, flexible, and on-demand launch services for small satellites, strengthening India's position in the global commercial space market. Complementing this effort, M/s Dhruva Space is establishing advanced space-grade solar array fabrication and testing facilities for spacecraft applications, creating critical domestic capabilities for the country's rapidly expanding space industry.

In the telecommunications sector, M/s Astrome Technologies Pvt. Ltd. developed the GigaMesh Solution, an advanced wireless communication

3D Choreographed Drone Light Shows

EV-based electric bull for agricultural applications

platform delivering reliable 4G/5G connectivity for defence, rural, and remote regions. The innovation is helping bridge the digital divide while strengthening secure communication infrastructure in strategically important areas.

Together, these initiatives highlight TDB's role in transforming cutting-edge ideas into globally competitive products, accelerating technological self-reliance, and positioning India as a leader in next-generation innovation.

TDB has also supported transformative innovations addressing critical societal and industrial needs. M/s Krishigati Private Limited developed an EV-based electric bull for agricultural applications, offering farmers a sustainable, energy-efficient, and cost-effective alternative to conventional farm machinery. Similarly, M/s Skyshade Daylight Private Limited pioneered an innovative daylight harvesting technology that captures and channels natural sunlight into indoor and underground spaces where daylight is otherwise

India's first single-piece 3D-printed rocket engine, mobile launch platforms "Agnibban" by M/s Agnikul

Innovative daylight technology by M/s Skyshade

GegaMesh by M/s Astrome

unavailable. By reducing dependence on artificial lighting, the technology enhances energy efficiency, lowers operating costs, and promotes sustainable infrastructure.

Recently, TDB has supported the commercialisation of several emerging and strategically important technologies across diverse sectors. These include the development of rare earth permanent magnets by M/s Midwest Advanced Materials Private Limited, strengthening India's capabilities in critical materials; the development of Type IV Composite CNG Cylinders by M/s NTF (India) Private Limited, promoting lightweight, high-pressure storage solutions for clean mobility; and the development of an innovative pothole repair solution " Ecofix" by M/s Ramuka Global Services Private Limited, enabling faster, durable, and cost-effective road maintenance. Development of a fuel refilling satellite By M/s Orbit Aid and many more. These projects are at different stages of development and commercialization. As they mature and reach wider deployment, they are expected to deliver significant economic and societal benefits while showcasing India's growing technological capabilities, innovation strength, and global competitiveness across strategic sectors.

Over the past thirty years, the Technology Development Board (TDB) has been a driving force in transforming India's innovation landscape by accelerating the commercialisation of indigenous technologies. TDB has bridged the critical gap between laboratory research and the marketplace. Its support has enabled Indian innovators to convert cutting-edge ideas into commercially successful products, strengthen domestic manufacturing, generate high-quality employment, and enhance the nation's technological competitiveness.

The present decade is widely regarded as the Decade of Technology, offering India an unprecedented opportunity to emerge as a global Technology leader. In this transformative era, TDB continues to serve as a key catalyst in fostering innovation-led industrial growth and accelerating the commercialization of indigenous technologies through its schemes and programmes. Building on a distinguished legacy of nearly three decades, TDB remains steadfast in its commitment to supporting visionary entrepreneurs, researchers, and industries that are shaping the technologies of tomorrow.

By advancing technology development and accelerating technology commercialisation, the Board will continue to play a pivotal role in realizing the national aspirations of Viksit Bharat, ensuring that Indian innovation drives sustainable economic growth and delivers product/ solutions with global impact.

Hon'ble Prime Minister Shri Narendra Modi interacting with representatives of successful startups during the National Technology Week 2023, organized by the Technology Development Board

Catalyzing Innovation and Partnerships

Advancing Indo-U.S. Science and Technology Cooperation through IUSSTF

Building Bridges in Science, Technology and Innovation

Dr Chaitali Bhattacharya

Interim Executive Director
Chief Science Officer
Indo-U.S. Science and Technology Forum (IUSSTF)

In an era defined by rapid technological disruptions and complex global challenges, scientific collaboration between nations is no longer just a diplomatic asset—it is a strategic necessity. At the vanguard of this collaborative frontier stands the **Indo-U.S. Science and Technology Forum (IUSSTF)**. Established in 2000 as an autonomous, bi-national organization funded equally by the Government of India (through the Department of Science & Technology) and the United States Government (through the Department of State), IUSSTF has spent more than 26 years transforming the landscape of bilateral scientific cooperation.

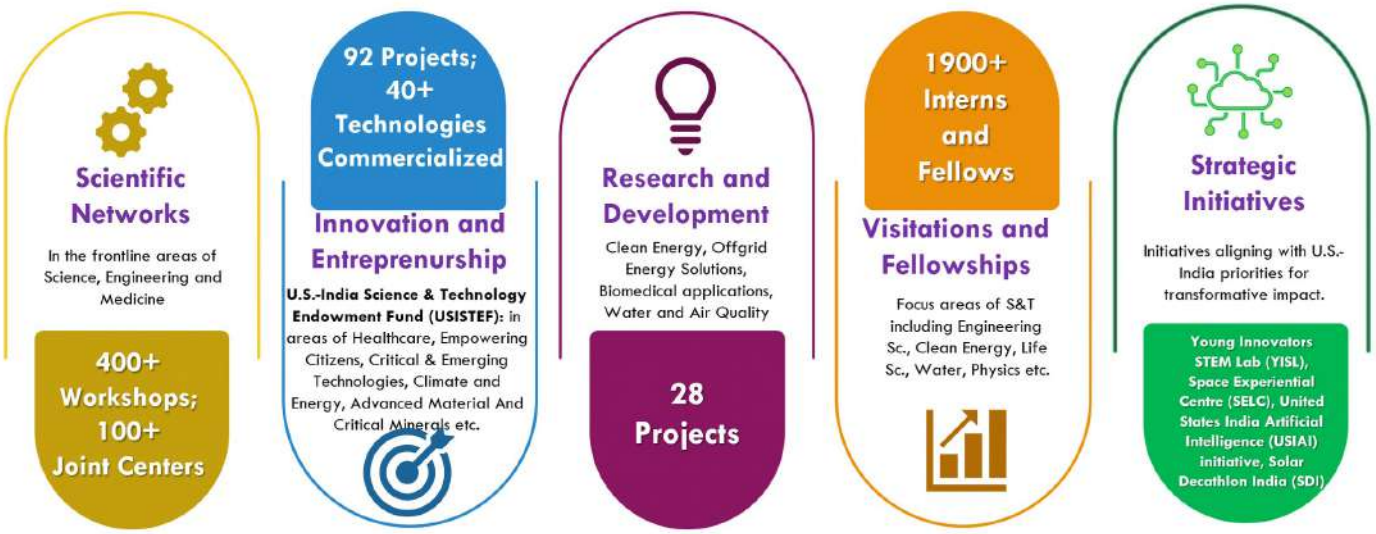
The relationship between India and the United States in science, technology, and innovation (STI) is anchored in shared democratic values, economic synergy, and a mutual commitment to global progress. As India marches resolutely toward its Viksit Bharat @2047 vision—aiming for a completely developed, self-reliant, and technologically advanced nation by its centenary of independence—its partnership with the United States acts as a vital force multiplier. IUSSTF serves as the vital institutional catalyst that translates high-level political alignment into tangible, ground-level scientific breakthroughs. Guided by evolving bilateral priorities such as the U.S.-India Partnership to Advance Clean Energy (PACE), the Initiative on Critical and Emerging Technologies (iCET), and Transforming Relationship Using Strategic Technologies (TRUST), the Forum continuously shapes its program portfolio to address emerging scientific and technological frontiers.

As the India-U.S. relationship evolves to address global challenges and emerging opportunities, science and technology have become central pillars of the strategic partnership. Through sustained engagement among researchers, innovators, entrepreneurs, academic institutions, industry, and policymakers, IUSSTF has created an ecosystem that enables co-creation, co-development, and co-investment in areas of mutual importance. The Forum's activities increasingly align with bilateral priorities such as artificial intelligence, quantum technologies, critical minerals, advanced manufacturing, biotechnology, health, water security, and climate resilience.

KEY ACHIEVEMENTS

CATALYZING BILATERAL COLLABORATIONS FOR OVER 25 YEARS

IUSSTF
Indo-US Science and Technology Forum



IUSSTF has supported exciting and innovative Indo-U.S. collaborative programs cutting across disciplines and institutions under the following portfolio:

- **Strategic Initiatives**
- **Innovation and Entrepreneurship**
- **Research and Development**
- **Scientific Networks**
- **Visitations and Fellowships**

Creating Scientific Networks and Institutional Partnerships

At the heart of IUSSTF's success lies its ability to connect people and institutions. S**cientific Networks** have long served as the foundation of the Forum's activities, enabling researchers from India and the United States to exchange ideas, identify common priorities, and develop long-term collaborative partnerships.

Over the years, IUSSTF has facilitated more than **404 bilateral workshops** and supported over **100 Virtual Networked Centres,** creating platforms for cooperation across frontier areas of science, engineering, medicine, energy, environment, and emerging technologies. These initiatives have brought together universities, research laboratories, industry partners, and government agencies from both countries to address challenges that no nation can solve alone.

Many of the collaborations that originated through these platforms have evolved into sustained research partnerships, joint publications, technology development efforts, and institutional linkages that continue to thrive today. By connecting scientific communities across borders, IUSSTF has helped establish a robust ecosystem for Indo-U.S. scientific engagement.

Advancing Collaborative Research for Global Challenges

Building upon these scientific networks, IUSSTF has supported collaborative research, and the most notable initiatives were the **Indo-U.S. Joint Clean Energy Research and Development Centre (JCERDC)**, which brought together leading researchers from both countries to work on smart grids, energy storage, solar energy, second-generation biofuels, and energy-efficient buildings. Similarly, the **PACEsetter Fund** supported innovative off-grid renewable energy technologies designed to improve energy access in underserved communities. Over the years, the Forum has supported **28 extramural research projects** and facilitated large-scale bilateral initiatives addressing critical challenges in clean energy, healthcare, environmental sustainability, and resource management.

IUSSTF has also facilitated collaborative programs focused on **water quality and air quality monitoring,** helping researchers address pressing environmental and

public health challenges. Partnerships in affordable healthcare technologies, including collaborations supported through the National Institute of Biomedical Imaging and Bioengineering (NIBIB-NIH), as well as multi-institutional academic research initiatives under the **Partnerships for International Research and Education (PIRE)** framework, further demonstrate the breadth of the Forum's research portfolio.

These initiatives underscore the value of combining scientific excellence with practical applications to generate solutions that benefit society while strengthening bilateral scientific cooperation.

Fostering Innovation and Technology Commercialisation

Innovation achieves its greatest impact when scientific discoveries are translated into products, services, and technologies that improve lives. Recognising this, IUSSTF has developed a strong portfolio of programs dedicated to innovation and entrepreneurship.

The flagship initiative under this pillar is the **U.S.-India Science and Technology Endowment Fund (USISTEF)**, a unique bilateral funding mechanism established to support joint technology development and commercialization by Indian and American innovators. Since its inception, the Fund has supported 92 collaborative projects and facilitated the commercialization of more than 40 technologies addressing challenges in healthcare, agriculture, clean energy, environmental sustainability, and emerging technologies.

The portfolio has evolved alongside bilateral priorities, supporting innovations under themes such as Healthy Individuals, Empowering Citizens, COVID-19 Response Technologies, Net Zero Energy Solutions, Artificial Intelligence, Quantum Technologies, Advanced Materials, and Critical Minerals.

Beyond USISTEF, IUSSTF has pioneered several impactful models to promote innovation-led entrepreneurship. **The India Innovation Growth Programme (IIGP)** enabled Indian innovators to access global markets

AI-Powered Pocket Medical Scanner Using S
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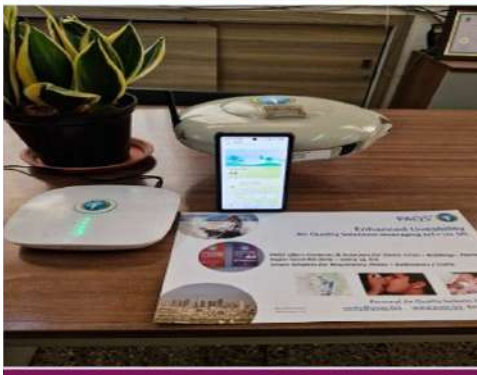
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Video Electroencephalography (VEEG) Solution for the Diagnosis and Monitoring of Neurological & Mental Health Conditions

ZincGel Battery for Renewable Microgrids

through mentoring, commercialization support, and engagement with U.S. innovation ecosystems. **The Women Entrepreneur Quest (WEQ)** helped identify and support women-led technology enterprises through mentorship, networking opportunities, and exposure to Silicon Valley's entrepreneurial ecosystem.

Together, these initiatives have demonstrated how bilateral partnerships can accelerate innovation, strengthen technology commercialization pathways, and create economic opportunities in both countries.

Glimpses of USISTEF Projects

As India and the United States deepen cooperation in critical and emerging technologies, IUSSTF has adapted its programmes to support new areas of strategic importance.

Recent initiatives have promoted joint innovation in artificial intelligence, quantum technologies, advanced materials, critical minerals, semiconductor-related technologies, cybersecurity, and climate technologies. These efforts support broader bilateral frameworks aimed at strengthening technology leadership, resilient supply chains, energy security, and innovation-driven economic growth.

Collaborative projects supported through these initiatives are developing solutions in areas such as AI-enabled healthcare, environmental monitoring, advanced sensing technologies, quantum devices, secure communications, sustainable energy storage, and next-generation manufacturing systems.

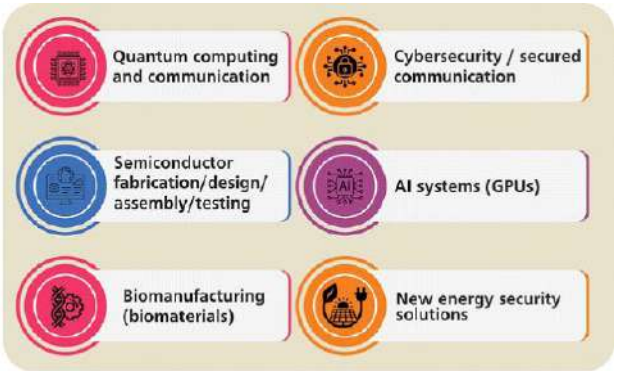
By connecting researchers, entrepreneurs, and technology developers from both countries, IUSSTF serves as an important implementation platform for translating strategic priorities into tangible collaborative outcomes.

Developing Future Scientific Leaders

People-to-people engagement remains one of the most significant pillars of Indo-U.S. scientific cooperation. Through fellowships, internships, research exchanges, and leadership programmes, IUSSTF has nurtured the next generation of scientists, engineers, innovators, and entrepreneurs.

Collectively, these programmes have supported more than 1,900 students, researchers, and professionals, providing opportunities to gain international research experience, access advanced facilities, and build global professional networks.

Call announced: 27 January 2025



Submission Deadline: 25th April 2025

Recent USISTEF Call themes aligning with US India Priority Areas

Flagship initiatives such as the **Khorana Program for Scholars, the IUSSTF-Viterbi Program, and the Water Advanced Research and Innovation (WARI) Fellowship** have enabled participants to work alongside leading faculty and researchers at premier institutions in both countries. Beyond technical training, these programmes foster long-term professional relationships that continue to generate collaborative research and innovation well beyond the duration of the fellowship.

While Khorana, WARI, and Viterbi remain the flagship active programs, IUSSTF has managed a portfolio of 15 visitation and fellowship initiatives over its history, supporting exchanges in areas ranging from biotechnology, clean energy, and water sciences to physics, gene editing, women in STEMM, and advanced engineering disciplines.

The growing success of these initiatives reflects the strong demand among young researchers for international scientific engagement and highlights the importance of human capital development in strengthening bilateral relations.

Aligning with Strategic and Emerging Technologies

As the India-U.S. partnership increasingly focuses on critical and emerging technologies, IUSSTF has expanded its role to support workforce development, innovation, and public engagement in areas of strategic importance.

The U.S.-India Artificial Intelligence (USIAI) Initiative served as a strategic platform for advancing bilateral cooperation in artificial intelligence by fostering research collaborations, supporting capacity building, and promoting the responsible development of AI technologies for societal benefit.

The Young Innovators STEM Lab (YISL), supported by the U.S. Department of State and implemented in partnership with STEAM Varsity, introduces students across India to emerging technologies such as Artificial Intelligence, Extended Reality (AR/VR), Robotics, and Design Thinking. Through immersive, hands-on learning experiences, the program equips young learners with skills essential for the future innovation economy.

Similarly, the **Space Experiential Learning Center (SELC)**, developed in collaboration with the American Center in New Delhi and Genex Space, provides students with opportunities to engage in astronomy, satellite engineering, space robotics, and mission design. Aligned with the U.S.-India TRUST Initiative, SELC demonstrates how educational partnerships can inspire the next generation of scientists and engineers.

Another landmark initiative, **Solar Decathlon India (SDI)**, brought together students, faculty, industry experts, and policymakers to design climate-responsive, net-zero buildings. The initiative fostered innovation in sustainable design while building awareness about energy efficiency and climate resilience among future architects and engineers.

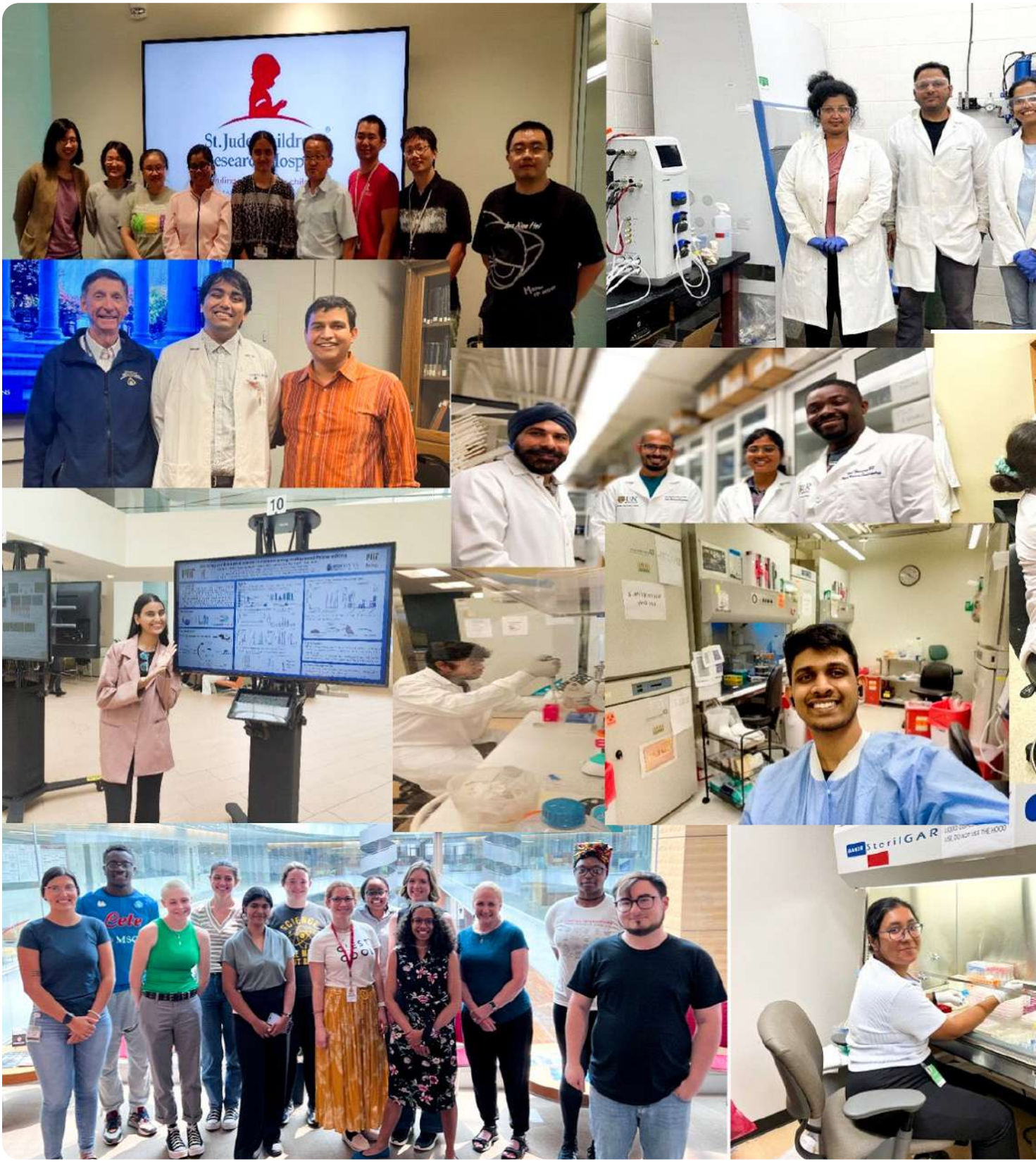
Collectively, these initiatives illustrate how IUSSTF has translated strategic priorities into practical opportunities for learning, innovation, and workforce development.

Looking Ahead

As India advances toward its vision of Viksit Bharat 2047 and the United States continues to invest in scientific leadership and technological innovation, the importance of strong international partnerships will only increase. Over the past quarter-century, IUSSTF has demonstrated the power of sustained bilateral cooperation in creating scientific knowledge, developing technologies, fostering entrepreneurship, and building human capital.

The Forum's journey reflects the evolution of the India-U.S. partnership itself—from scientific exchanges to strategic collaboration, from research partnerships to innovation ecosystems, and from individual projects to enduring institutional relationships. By continuing to catalyze collaboration across science, technology, innovation, and education, IUSSTF remains committed to advancing shared prosperity and addressing global challenges through the collective strength of Indian and American ingenuity.

IUS
WARI Interns, Fellows



STF
and Khorana Scholars

IGSTC: Shaping Innovation through Indo-German Cooperation

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Scientific advancement in the twenty-first century is increasingly fuelled by collaboration rather than competition. The scale and complexity of emerging challenges whether related to climate resilience, sustainable industrialisation, clean energy, public health, resource efficiency, or digital transformation have successfully demonstrated that breakthrough solutions often emerge when nations coalesce their skill, expertise, infrastructure, and innovation capabilities. In this evolving landscape, international partnerships have become far more than diplomatic instruments; they have emerged as strategic platforms for generating knowledge, accelerating technological progress, and translating research into societal and economic value.

The Indo-German partnership in science and technology exemplifies this philosophy in action. Over the decades, it has grown into a robust and forward-looking framework that has continuously adapted to emerging socio-technical priorities while retaining its foundational principles of co-existence, reliability, reciprocity, and shared excellence. As the partnership expanded in scope and ambition, the emphasis gradually shifted from scientific collaboration alone towards innovation-led cooperation capable of delivering measurable outcomes. The **Indo-German Science & Technology Centre (IGSTC)** emerged as a landmark initiative in 2010 with the budget of €8 Million per year. By fostering industry-oriented research, supporting technology development, and nurturing innovation-driven partnerships. IGSTC has become one of the most prominent manifestations of Indo-German cooperation and a trusted framework for translating knowledge to market-oriented innovation.

Journey of Indo-German S&T Cooperation

Since its inception in 1974, the Indo-German partnership in science and technology has stands today as one of the most enduring and dynamic examples of international scientific cooperation. The foundations of this partnership were laid during the formative years of India's scientific and industrial renaissance, when Germany emerged as a trusted partner in

strengthening the country's higher education and research landscape. Spanning more than five decades, this relationship has evolved from modest academic and technical exchanges into a comprehensive innovation ecosystem that connects governments, research institutions, universities, industries, and scientific communities across both nations. Its strength lies not merely in its longevity, but in its remarkable ability to adapt to changing scientific priorities, technological transformations, and societal needs while maintaining a shared commitment to excellence, mutual trust, and knowledge-driven development. The breadth of this partnership is reflected in the diversity of its flagship collaborations. From pioneering cooperation between ISRO and DLR in space research and satellite applications, to joint biomedical initiatives linking ICMR with leading German research organisations, Indo-German cooperation has consistently addressed scientific challenges of global relevance. The partnership further expanded into advanced manufacturing and industrial innovation through the CSIR–Fraunhofer collaboration, DBT-BMBF (now BMFTR) Special Arrangement for Cooperation in Biotechnology, MOU between ICMR and Helmholtz Association for Setting up of Indo German Science Centre for Infectious Diseases. Collectively, these landmark initiatives exemplify a partnership that has successfully bridged disciplines, harness cross-border innovation, and transforming scientific collaboration into a strategic instrument for technological advancement and socio-economic progress.

What began as support for academic capacity building gradually matured into a wide-spectrum scientific engagement, fostering unwavering institutional linkages and creating opportunities for generations of researchers to collaborate, exchange ideas, and jointly explore solutions to complex challenges. Over the decades, this cooperation expanded steadily across an extensive range of scientific fields, encompassing engineering, medicine, biology, artificial intelligence, quantum technology, space technology, industry 4.0, advanced materials, environmental research, sustainable technologies, digital innovation, and several other frontier domains. This evolution transformed the deep-rooted partnership from a collection of bilateral initiatives into a thriving, interconnected and synergistic network where vision, knowledge, expertise, infrastructure, and innovation capabilities could be shared for mutual benefit.

The continuing dynamism of this partnership was further demonstrated during the Indo-German Joint Committee Meeting held in November 2025, co-chaired by Prof. Abhay Karandikar, Secretary, DST and Dr. Silke Launert, Parliamentary State Secretary, BMFTR. The meeting reaffirmed the shared commitment of both countries to further strengthening bilateral science, technology and innovation cooperation, while also underscoring the growing importance of participation in major international research infrastructures such as FAIR and DESY. As S&T engagement deepened, it also became increasingly aligned with broader

Joint Indo-German Committee meeting at DST, India

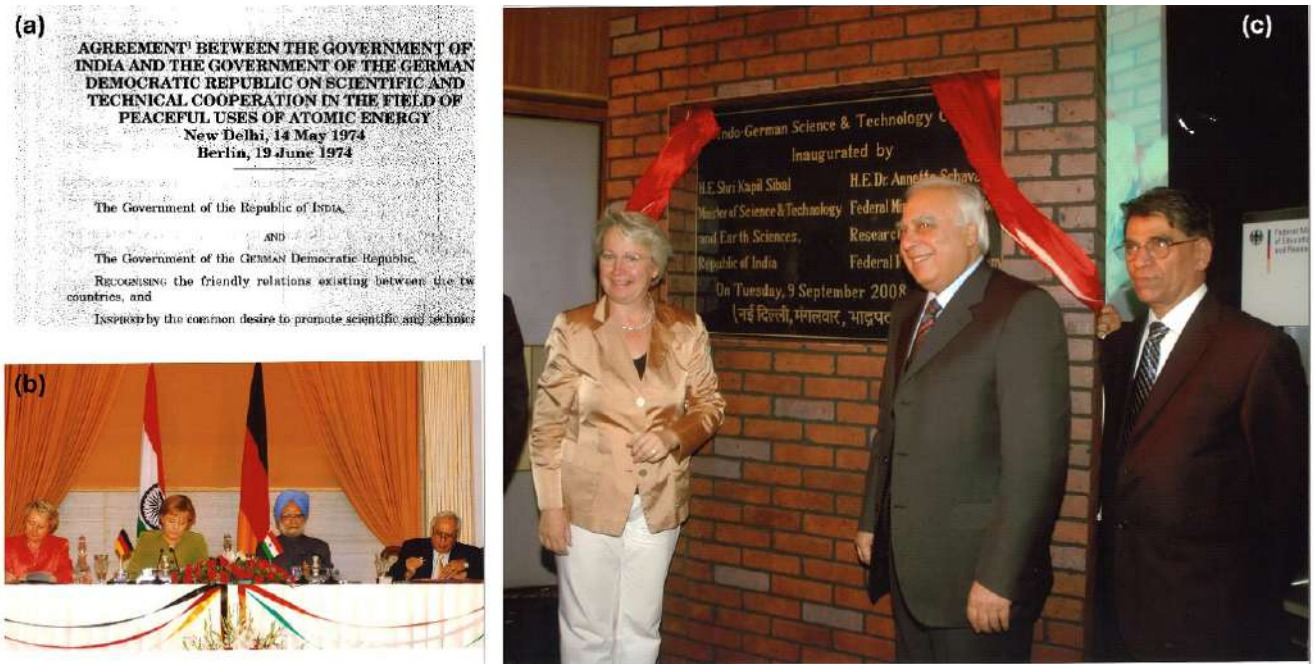
developmental aspirations, contributing to sustainable growth, technological competitiveness, and societal well-being in both countries. Through decades of continuous engagement, India and Germany have cultivated a culture of collaboration characterised by openness, reciprocity, and long-term vision. The resulting network of institutional partnerships, researcher exchanges, joint programmes, and collaborative platforms has generated a resilient framework capable of responding to new opportunities and addressing in-time priorities. This long-standing cooperation has enabled both countries to move beyond traditional models of engagement and embrace a more strategic and outcome-oriented approach to international scientific collaboration.

Genesis and Growth of IGSTC

As the partnership matured and innovation assumed a central role in economic and technological advancement, the need for stronger integration between scientific research and industrial application became increasingly evident. Conceived as a unique platform to strengthen industry-oriented research and innovation partnerships, IGSTC introduced a new dimension to Indo-German engagement by bringing together academia, research organisations, industries, start-ups, and innovators from both countries. IGSTC has established itself as a flagship institution within the Indo-German cooperation landscape. By fostering collaborative research, promoting innovation deployment, supporting researcher and industry mobility, and encouraging the translation of scientific knowledge into practical solutions, it has successfully bridged the gap between laboratories and markets. More importantly, it has demonstrated how bilateral cooperation can generate tangible socio-economic impact while nurturing long-term innovation networks. Unlike many conventional cooperation mechanisms that primarily focus on academic exchange or research collaboration, IGSTC operates at the intersection of science, technology, innovation, and industry. Its distinguishing strength lies in its ability to create demand-driven partnerships where researchers, industrial stakeholders, entrepreneurs, and policymakers jointly shape innovation pathways from concept to commercialisation. By integrating scientific excellence with industrial relevance and market applicability, IGSTC has nurtured a partnership model that is both outcome-oriented and future-ready.

IGSTC, jointly established by Department of Science & Technology (DST) and Federal Ministry of Research, Technology and Space (BMFTR) has evolved a holistic cooperation framework that supports the entire lifecycle of bilateral engagement—from initiating scientific dialogue and building networks, to fostering collaborative research, developing technologies, strengthening industrial linkages, and cultivating the next generation of innovators. This integrated approach has enabled IGSTC to emerge as a unique catalyst within the Indo-German science, technology, and innovation landscape.

The year 2024 marked an important milestone. The Golden Jubilee celebration at New Delhi offered an opportunity to reflect on five decades of cooperation while looking ahead to new areas of collaboration. Bringing



(a) Indo-German S&T Cooperation signed on 1974. (b) Joint Statement on the Further Development of the Partnership between India and Germany. (c) Inauguration of Indo-German Science & Technology Centre (IGSTC). Photo courtesy: Press Information Bureau (PIB)

together policymakers, researchers, industry leaders, innovators, and funding agencies from both countries, the celebration served as a powerful reaffirmation of the partnership's strategic importance and future potential. It highlighted not only the achievements of the past but also the growing readiness of India and Germany to jointly address global concerns through science, technology, and innovation. The occasion underscored a common conviction that the next chapter of bilateral cooperation would be defined not merely by scientific excellence, but by its capacity to deliver transformative solutions for a rapidly evolving world.

Celebration of 50th years of Indo-German S&T Cooperation at New Delhi

IGSTC Mandate and Programme Portfolio

Today, IGSTC represents far more than an institutional mechanism; it embodies the evolution of Indo-German scientific relations from cooperation to co-creation and from knowledge exchange to innovation-driven partnership. As Indo-German S&T cooperation advances into its next phase, IGSTC stands as a stellar testament to what sustained vision, mutual confidence, and shared scientific ambition can achieve in building a future-oriented and globally relevant partnership.

At the heart of this framework is the flagship 2+2 programme, a distinctive model that brings together academia and industry from both India and Germany in equal partnership and onus. By aligning scientific excellence with industrial relevance, the programme encourages the co-development of technologies capable of addressing real-world needs. The initiative has successfully transformed collaborative research into tangible outcomes, including prototypes, patents, pilot-scale demonstrations, and market-oriented solutions across strategically important sectors ranging from advanced manufacturing and sustainable energy to artificial intelligence, bioeconomy, and digital technologies and many more. The provision for Phase-II support for promising deliberations further strengthens this innovation pipeline by facilitating the critical

IGSTC programme portfolio

transition from laboratory validation to industrial implementation. This innovation-driven pillar is further strengthened by a vibrant cooperation architecture of networking and capacity-building programmes designed to foster collaboration and knowledge exchange. The Open Call for Indo-German Bilateral Workshops serves as a fertile ground where emerging ideas are discussed and refined through intriguing dialogue among researchers, industry experts, and policymakers. These workshops act as incubators for future collaborative projects, creating opportunities for interdisciplinary engagement and identifying complementary expertise across both countries. In many instances, discussions initiated through these platforms mature into larger research partnerships, thereby ensuring a continuous flow of fresh ideas into the bilateral cooperation landscape.

Recognising that importance of sustainable innovation partnership, IGSTC has placed equal emphasis on capacity development and mobility. Programmes such as the Industrial Fellowship and the Paired Early Career Fellowship in Applied Research (PECFAR) provide young researchers with immersive exposure to industrial environments, advanced research facilities, and innovation cultures in the partner country. These initiatives facilitate the cross-fertilisation of ideas while nurturing a generation of scientists capable of navigating both academic inquiry and technological application. Equally significant is the WISER programme, which has strengthened the participation and leadership of women researchers in bilateral collaborations, reinforcing diversity as a driver of scientific excellence and innovation.

The portfolio is further reinforced by agile instruments such as the Small Immediate Need Grants (SING), which provide rapid support for emerging opportunities, exploratory collaborations, technology demonstrations, and time-sensitive innovation activities. Together, these programmes function as interconnected components of a larger strategic architecture. Workshops generate ideas, fellowships cultivate talent, WISER broadens participation, SING accelerates emerging opportunities, and the 2+2 programme transforms collaborative potential into impactful cohesive innovation. This seamless progression distinguishes IGSTC from conventional funding mechanisms. Rather than supporting isolated activities, it has created a self-sustaining collaborative platform where partnerships continuously evolve, capabilities are strengthened, and innovation is translated into outcomes. In doing so, IGSTC has not only enhanced cross border collaboration but has also established a durable model of international collaboration that integrates research, industry, mobility, inclusivity, and innovation into a single coherent vision.

Key Success Stories contributing to national tech missions of India and Germany

The success of a research partnership is defined by its ability to convert scientific ambition into tangible outcomes—advancing technologies, empowering industries, and delivering solutions to pressing societal priorities. IGSTC through its flagship 2+2 programme, has demonstrated precisely this capability. By bringing together research institutions and industries from both India and Germany in a balanced partnership model, IGSTC has cultivated a dynamic partnership structure where scientific excellence converges with industrial relevance. Several projects emerging from this framework have distinguished themselves not only through technological ingenuity but also through their capacity to real world deployment across sectors and geographies. The thematic focus of the IGSTC 2+2 programme mirrors the strategic technology priorities of both India and Germany. The programme has supported collaborative research in advanced manufacturing, new materials, artificial intelligence, IOT, bioeconomy, sustainable production, circular economy, health technologies, smart cities, green technologies, and water sustainability. These investments resonate strongly with India's National Missions on Quantum Technologies, Cyber-Physical Systems, Climate Action, and the broader national agenda for clean energy transition, sustainable manufacturing, and Atmanirbhar Bharat initiative. Simultaneously, they align with Germany's High-Tech Agenda, which places particular emphasis on key enabling technologies, digital transformation, semiconductors, climate-neutral industrial processes, circular resource utilisation, future materials, and AI-driven innovation. Through these strategic efforts, IGSTC has enabled the translation of bilateral excellence into technologies that drive industrial sustainability, resource efficiency, and innovation-led growth.

One of the most compelling examples emerges from the field of water sustainability. As industries worldwide grapple with increasing water scarcity and stricter environmental regulations, the challenge of wastewater treatment and resource recovery has assumed unprecedented significance. Addressing this critical need, the EfectroH2O (Effect-based monitoring

demonstrates efficiency of electrically-driven water treatment processes to remove salts and micropollutants from process water) project united the expertise of IIT Madras, Tamil Nadu Water Investment Company Ltd., Goethe University Frankfurt, RWTH Aachen University, and Ibacon GmbH to develop an innovative approach for industrial wastewater management. The consortium focused on enhancing electrically driven water treatment technologies capable of removing salts and micropollutants while improving the techno-economic feasibility of Zero Liquid Discharge (ZLD) systems. What makes EfectroH2O particularly remarkable is its successful transition from laboratory research to field demonstration. The technology was validated through a pilot-scale installation at a Common Effluent Treatment Plant in Tiruppur, one of India's largest textile manufacturing clusters. By enabling improved recycling of process water and recovery of valuable resources, the project addresses both environmental sustainability and industrial competitiveness. Beyond technological advancement, the initiative exemplifies how bilateral cooperation can directly contribute to global sustainability goals by delivering practical solutions for water-stressed regions.

A second success story illustrates the partnership's contribution towards sustainable mobility and climate action. The transition towards low-carbon transportation remains one of the defining technological imperatives of current era, particularly in countries where two-wheelers constitute a dominant mode of personal mobility. Recognising this opportunity, researchers and industrial partners from IIT Madras, TVS Motor Company, RWTH Aachen University, and VEMAC GmbH joined forces under the HERCET (Development and validation of a cost-effective hybrid electric drive solution for small two wheelers for reducing CO2 emission) project to develop a cost-effective hybrid electric drive solution tailored for small two-wheelers. The project successfully integrated a hybrid electric drive system into a commercially available scooter platform while maintaining affordability and suitability for Indian operating conditions. Extensive calibration and validation studies demonstrated the potential to significantly reduce fuel consumption and carbon emissions without compromising performance. More importantly, HERCET showcased the strength of cross-border innovation, combining German expertise in vehicle systems engineering with

(a) EffectroH2O: Wastewater Treatment Plant (WTP) integrating AOP and CDI installed at CETP, Tiruppur. (b) HERCET: Demonstration of TVS Jupiter scooter with developed Hybrid Electric Drive. (c) add-bite: Designed Total Mandibular Joint (TMJ) implanted for maxillofacial reconstruction

India's deep understanding of cost-effective mobility solutions. The resulting prototype represents far more than a technological achievement; it offers a pathway towards cleaner urban transportation and reduced environmental footprint. In the ear of decarbonisation and net-zero sustainability, HERCET stands as an exemplary demonstration of how collaborative research can accelerate the development of practical and scalable climate solutions.

While sustainability and mobility represent major pillars of contemporary innovation, the future of manufacturing is being shaped by a different revolution—additive manufacturing. Here too, IGSTC-supported projects have produced outcomes of significant strategic importance. Among them, the add-bite (Development of patient specific additively manufactured mandibular implants with biotechnology inspired functional lattice structures) project represents a particularly striking example of how advanced manufacturing can transform healthcare. Bringing together IIT Delhi, AIIMS New Delhi, Tata Steel Ltd., Karlsruhe Institute of Technology, and OTEC Präzisionsfinish GmbH, the project sought to develop patient-specific mandibular implants using additive manufacturing and bio-inspired lattice structures. The consortium successfully engineered a novel Total Mandibular Joint (TMJ) implant designed to replicate the complex geometry and functional characteristics of human bone. Leveraging advanced computational design, metal additive manufacturing, and sophisticated post-processing technologies, the project produced biocompatible implants with optimised mechanical properties and enhanced potential for osseointegration.

The resulting technology has opened new possibilities for personalised maxillofacial reconstruction, offering patients improved functional outcomes, reduced surgical complexity, and enhanced quality of life. Equally important, the project demonstrates how the convergence of engineering, medicine, materials science, and manufacturing can generate transformative

Visit of Hon'ble Prime Minister of India to the greenhouse at IARI built under IGSTC 2+2 Project Sensvert

healthcare solutions. It also highlights the growing role of additive manufacturing as a strategic technology capable of redefining industrial and medical production paradigms.

These projects underscore the distinctive value proposition of IGSTC's 2+2 model. Unlike conventional research collaborations, which often conclude at the stage of scientific discovery, IGSTC actively encourages the translation of knowledge into innovation by embedding industry participation from the very outset.

This approach not only accelerates technology translation but also enhances the prospects for adoption, scale-up, and market impact. The result is a cooperation framework that delivers scientific excellence while simultaneously strengthening industrial competitiveness and societal resilience. A particularly noteworthy reflection to the impact and visibility of the IGSTC 2+2 programme was the visit of the Hon'ble Prime Minister of India, Shri Narendra Modi, to the advanced greenhouse facility for protected cultivation established at the Indian Agricultural Research Institute (IARI), New Delhi, under the Indo-German 2+2 project SENSVERT in December 2025.

The visit highlighted the project's contribution to advancing climate-smart and technology-driven agriculture and showcased India's growing leadership in agricultural science, innovation, and sustainable food production. Beyond individual project successes, the broader impact of IGSTC is reflected in the energetic ecosystem it has nurtured over the years. Through its integrated portfolio of collaborative R&D&I projects, workshops, fellowships, WISER, and agile support mechanisms, IGSTC has facilitated the engagement of more than 7,000 scientists, innovators, industry professionals, and early-career researchers from both countries.

The Centre has supported over 80 bilateral workshops, enabled more than 2000 institutional and industrial linkages, and fostered a rich body of scientific outputs, including thousands of joint publications, hundreds of citations, patents, and technology developments. Collectively, these achievements illustrate how IGSTC has flourished beyond a funding platform into a strategic catalyst of Indo-German innovation diplomacy, creating enduring partnerships, strengthening innovation capacity, and generating tangible socio-economic impact across India and Germany.

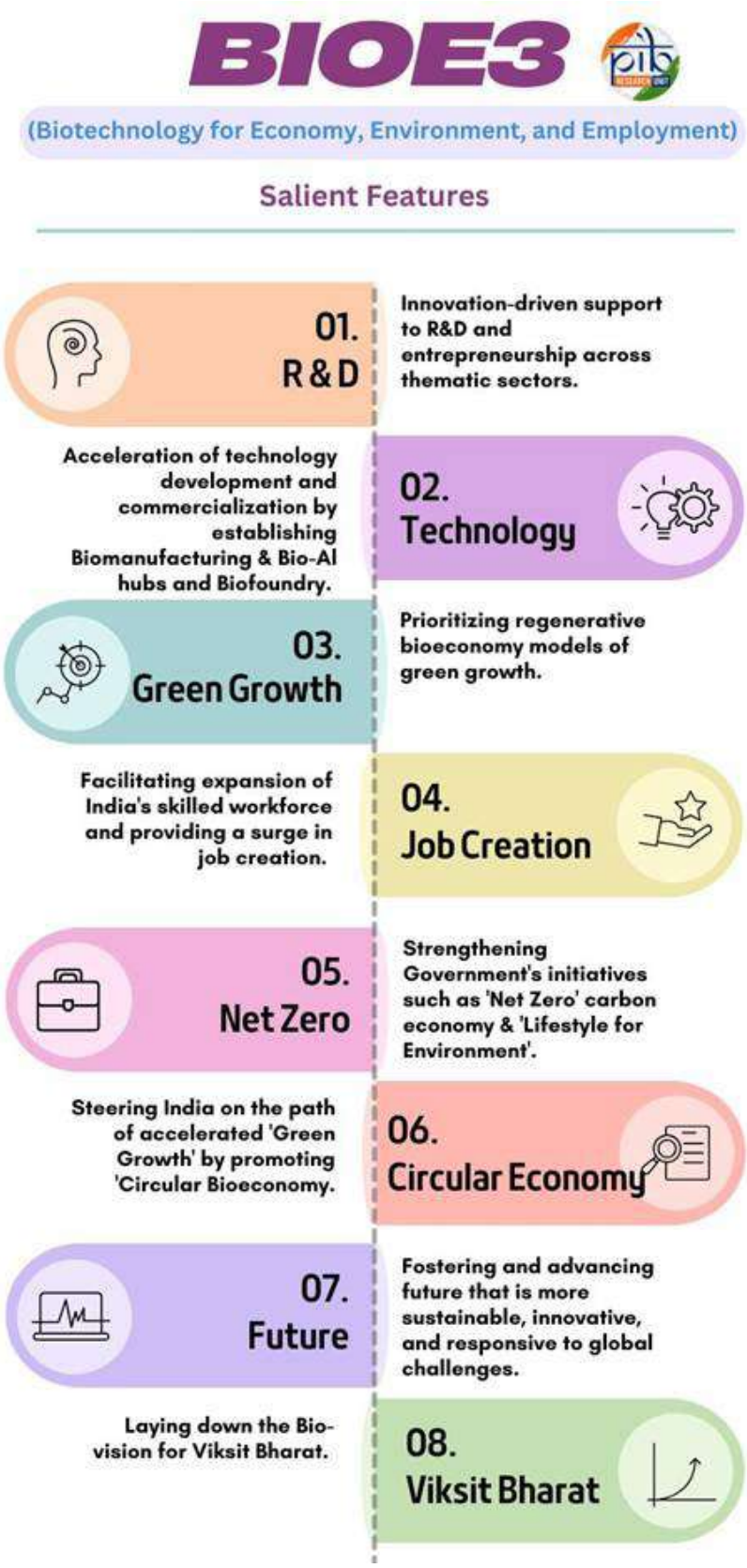
Strategies for the Future

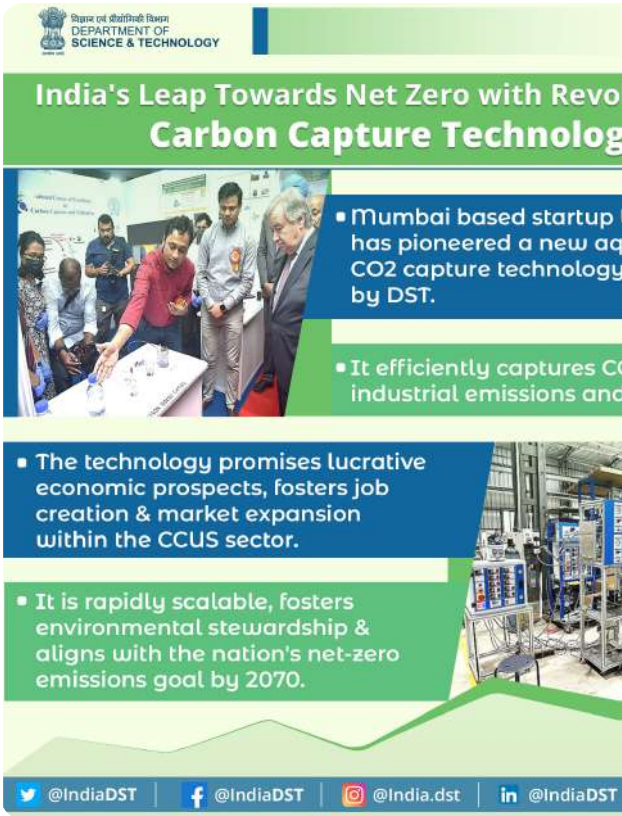
As India and Germany advance towards a new phase of scientific and technological cooperation, the partnership stands at the intersection of two ambitious national visions: India's aspiration for technological self-reliance, sustainable development, and global leadership in innovation, and Germany's commitment to pioneering future technologies, climate neutrality, industrial transformation, and a knowledge-driven economy.

By enabling partnerships that accelerate the journey from scientific discovery to industrial application, IGSTC will remain a key architect of the future Indo-German relationship, where success is measured not only by the generation of fundamental knowledge, but by its capacity to deliver transformative, real-world impact. As global challenges become more interconnected and complex, the emphasis must shift towards co-developing scalable technologies, innovation-driven industries, and future-ready solutions that enhance economic competitiveness, environmental stewardship, and societal wellbeing.

Anchored in enduring perseverance and guided by a shared commitment to excellence, innovation, and sustainability, Indo-German S&T cooperation is positioned to evolve from a successful bilateral partnership into a globally influential innovation alliance, one that not only advances national priorities but also contributes meaningfully to addressing global challenges and building a more resilient, technologically empowered, and prosperous civilisation.

A Glimpse of Ma





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