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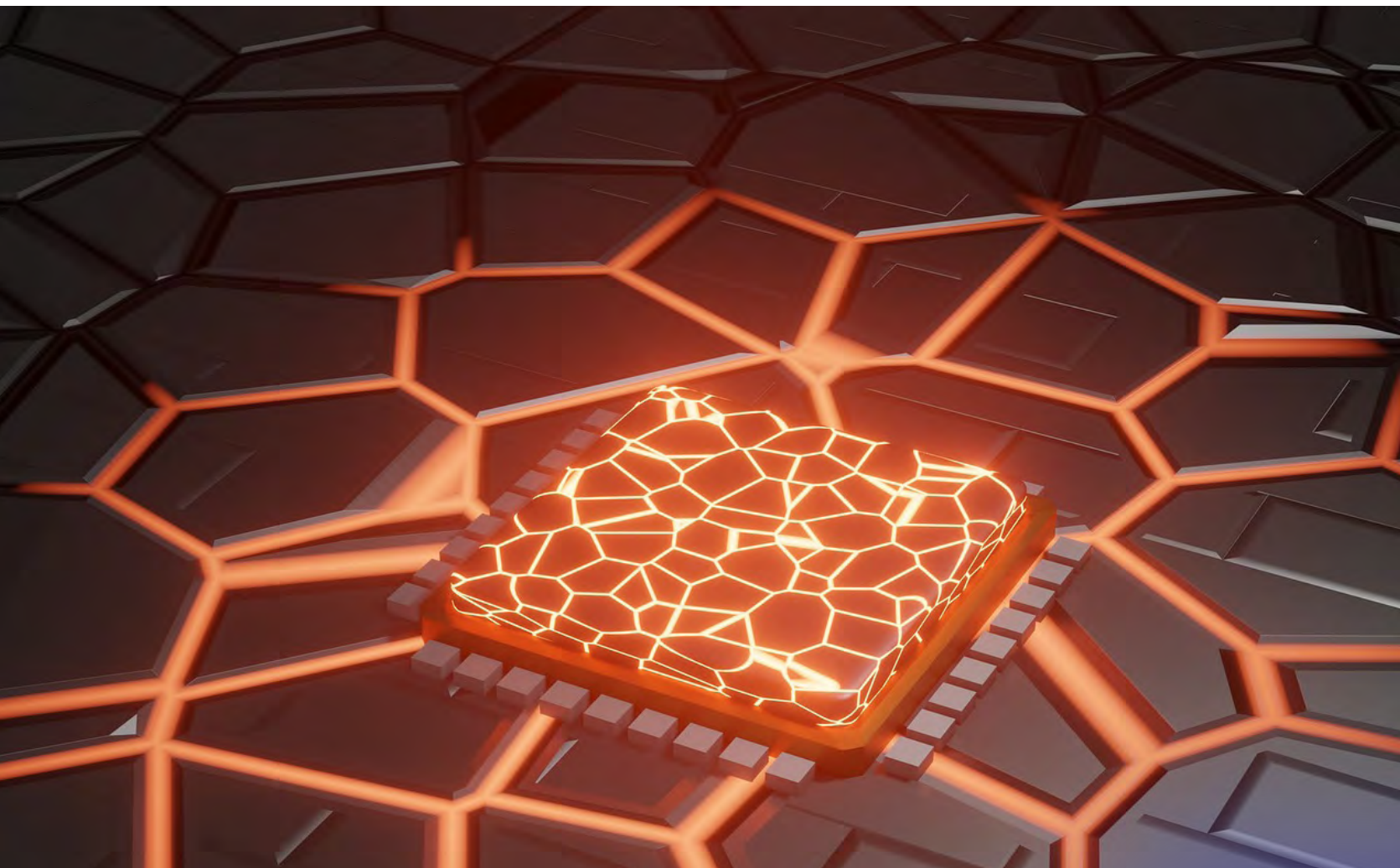

SPECIAL ISSUE

TECHNOLOGY DIALOGUE 2025
Exploring New Frontiers in Technology Diplomacy

TECHNOLOGY DIPLOMACY

in collaboration with
Office of the Principal Scientific Adviser to the Government of India

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Science Diplomacy

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This Science Digest is open to new ideas, valid criticism and constructive feedback. If there is any science diplomacy/ policy related event which requires wider outreach, please share it with us. We welcome your articles/ feedback/ suggestions at scidip@niscpr.res.in

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The Evolving Nature of Technology Diplomacy

Prof. Ajay Kumar Sood
Principal Scientific Adviser to the Government of India

Technology plays a critical role in shaping international relations by influencing policy frameworks, driving economic growth, and bolstering national security. In the context of international relations, technology now transcends traditional boundaries, influencing various sectors, including health, energy, trade and more. It also serves as a tool for cooperation, competition, and security, ultimately redefining global partnerships and engagements. With the rise of disruptive technologies, I believe a comprehensive approach is essential to fully leverage their socio-economic and strategic benefits for every stakeholder, necessitating a platform to create synergy among diverse participants in the technology ecosystem.

This need for an inclusive platform for a comprehensive approach to technology diplomacy led us to organise 'Technology Dialogue 2025'. As the Principal Scientific Adviser to the Government of India, I recently had the opportunity to co-host this technology policy summit, jointly organised by my office, the Ministry of External Affairs, and the Indian Institute of Science (IISc) in Bengaluru. With the theme "Exploring new frontiers in technology diplomacy," the summit provided an avenue for us to explore new opportunities in technology diplomacy efforts. The subsequent pages of this digest capture the rich discussions from various panels and sessions held during the two-day dialogue, offering readers valuable insights into the multifaceted dimensions of technology diplomacy explored during this landmark event.

For India to play an agenda-setting role on the global stage, especially in transformative and emerging areas of technology, I recognise that a comprehensive and strategic approach to international technology engagement is critical. Our country requires a streamlined framework that comprises aspects such as encouraging foreign direct investment (FDI), fostering deep-tech innovations, promoting technology transfer, refining intellectual property rights (IPR), addressing anti-dumping measures, developing governance frameworks for data and disruptive technologies, engaging the scientific diaspora, and enhancing academic and workforce mobility.

In my view, a dynamic, 360-degree approach, informed by domestic, international, and sectoral insights, is required to adopt a comprehensive International Technology Engagement Framework (ITEF) for India. The vision of ITEF should evolve alongside changing global contexts and be supported by a robust conceptual foundation. The evolving strategic technology partnerships with key partner countries, such as the India-US TRUST initiative, QUAD's cooperation on critical and emerging technologies, India-EU Technology and Trade Council (TTC), India-UK Technology Security Initiative (TSI), and many such upcoming initiatives, are a result of our vision to bring technology to the centre stage of international engagements. As you will discover in this compilation, many of these partnerships were discussed during the Technology Dialogue panels.

I firmly believe it is essential to have a long-term vision and a practical toolkit, both facilitated by a roadmap to effectively navigate critical, emerging, and disruptive technologies. For this, we require

streamlined efforts across academic partnerships, workforce mobility, deep-tech startups, technology transfer, economic trade relations, and security, as discussed across panels during the two-day event.

Against the backdrop of India's evolving technology partnerships with global partners, I have observed that global technology engagements are anchored through a country's domestic efforts and vice-versa. As technology partnerships evolve, it is essential to have synergistic efforts among nations to ensure a meaningful impact. For instance, the Chief Science Advisers' Roundtable — an initiative led by my office and conceptualised during India's G20 Presidency — enabled a global platform among the Chief Science Advisers for science diplomacy. This platform focused on three key areas: addressing common priorities such as leveraging opportunities in One Health for better disease prevention, control, and pandemic preparedness; synergising global efforts to expand access to scholarly scientific knowledge; and ensuring equity, diversity, inclusion and accessibility within the Science and Technology Ecosystem. I am pleased to note that these three priority areas have notably found their way into not only our national science and technology agendas but also some of the key international engagements.

For instance, the multilateral deliberations on the One Health framework led to fostering India's engagement with the One Health Quadripartite — Food and Agriculture Organization of the United Nations (FAO), the United Nations Environment Programme (UNEP), the World Health Organization (WHO), and the World Organisation for Animal Health (WOAH). It has also strengthened connections and continued engagements between One Health institutes in various countries. Similarly, India's recently launched 'One Nation One Subscription' initiative derived some learnings from our priority to synergise global efforts to expand access to scholarly scientific knowledge. Previous discussions fostered by my office on ensuring diversity, equity, inclusion and accessibility within the Science and Technology Ecosystem raised an important issue: the lack of disaggregated data on inclusivity indicators. Inspired by these discussions, we have initiated efforts to develop an indicator-based framework for India. These inclusivity issues were also recognised by both national and international panellists, further validating India's problem recognition and resolution efforts.

A key takeaway from my experience is that synergistic efforts among the stakeholders are essential in ensuring a meaningful impact on international technology engagement. Industry stakeholders are a crucial part of any international engagement, and thus, I emphasise the importance of forging comprehensive partnerships with multinational corporations (MNCs), startups, and private foundations. Trade agreements must protect national interests while enabling technology-driven economic growth through market access and technology transfer.

To facilitate informed discussions, promote equitable collaborations, and ensure reciprocity in international engagements, I consider it essential to provide operational tools and easy-to-adapt interventions to Indian missions abroad. This would enable effective engagement with foreign counterparts on technology-related issues to maximise strategic, economic, and innovation-driven outcomes.

As we move forward, I envision India striving to expand its international technology engagement footprints, not just in its scope and reach but also in its depth and intensity. I hope this collection of articles from the Technology Dialogue 2025 will serve as both a record of our deliberations and a roadmap for future action in the dynamic field of technology diplomacy.

Architecting a Technology-Driven Future: Shaping Global Tech Partnerships through India's Engagement Framework*

As the fourth industrial revolution transforms the global landscape, technology has evolved from being a mere catalyst for progress to becoming the central pillar of geopolitical influence and supremacy. In this rapidly changing environment, India—the world's most populous country—stands poised to become a key player in the evolving world order.

> ***In the past, nations vied for supremacy based on their defence capabilities. Today, the competition revolves around technological leadership.***
>
> **Dr Kiran Mazumdar-Shaw,**
> **Chairperson and Managing Director of Biocon**

Dr Kiran Mazumdar-Shaw, Chairperson and Managing Director of Biocon, delivering the special address

* *This article draws insights from the Inaugural Session titled 'India's International Technology Engagement Framework' of the Technology Dialogue 2025.*

Until recently, viewing technology merely as a tool to enhance existing bilateral and multilateral partnerships was sufficient. However, as technology takes centre stage in international relations, developing a comprehensive framework that places technology and geopolitics at its core is essential—one that guides how technology engagements are forged in this new era.

India's Approach

India's strategy for technology engagement builds upon two critical foundations: its robust digital infrastructure and expansive human capital.

The country's digital infrastructure has transcended mere technological innovation to become a cornerstone of its geopolitical strategy. The Unified Payments Interface (UPI) exemplifies this transformation, processing over 16.6 billion transactions in October 2024 alone—representing nearly 80% of the country's digital payments and demonstrating a scale that confers significant global influence. Similarly, the Ayushman Bharat Digital Mission (ABDM) has created over 67 crore health accounts and integrated more than 130,000 health facilities.

Inaugural Session. From left: Prof. G.K. Ananthasuresh, Prof. G. Rangarajan, Prof. Ajay Kumar Sood, H.E. Pavan Kapoor, Dr Kiran Mazumdar-Shaw

These digital public infrastructures represent a new form of soft power, allowing India to export governance models and technical standards while bolstering its geopolitical positioning in an increasingly digital world order. On aspects of digital inclusion, India's initiatives in digital public infrastructure (DPI) have gained international acclaim. The Aadhaar programme, which has registered over 94% of India's population, has been praised by Nobel laureate Paul Romer as "the most sophisticated ID program in the world."

The backbone of India's technology ecosystem—its workforce and industry—has also shown remarkable growth. The country is now home to over 150,000 startups and more than 100 unicorns. India produces one of the world's largest STEM workforce, adding approximately 2 million graduates annually. With over 5 million programmers, India has emerged as a leading talent pool for artificial intelligence (AI), addressing a critical global shortage. This burgeoning industry and skilled workforce are central to India's international engagements and underscore its leadership potential.

With the strength of its talent, the dynamism of its startup ecosystem, and the support of its global diaspora, India is set to lead the world into a future driven by sustainable and inclusive technology.

Dr Jitendra Singh, Union Minister of State (Independent Charge), Ministry of Science and Technology, Government of India

Dr Jitendra Singh, Union Minister of State (Independent Charge), Ministry of Science and Technology, Government of India, delivering the keynote address

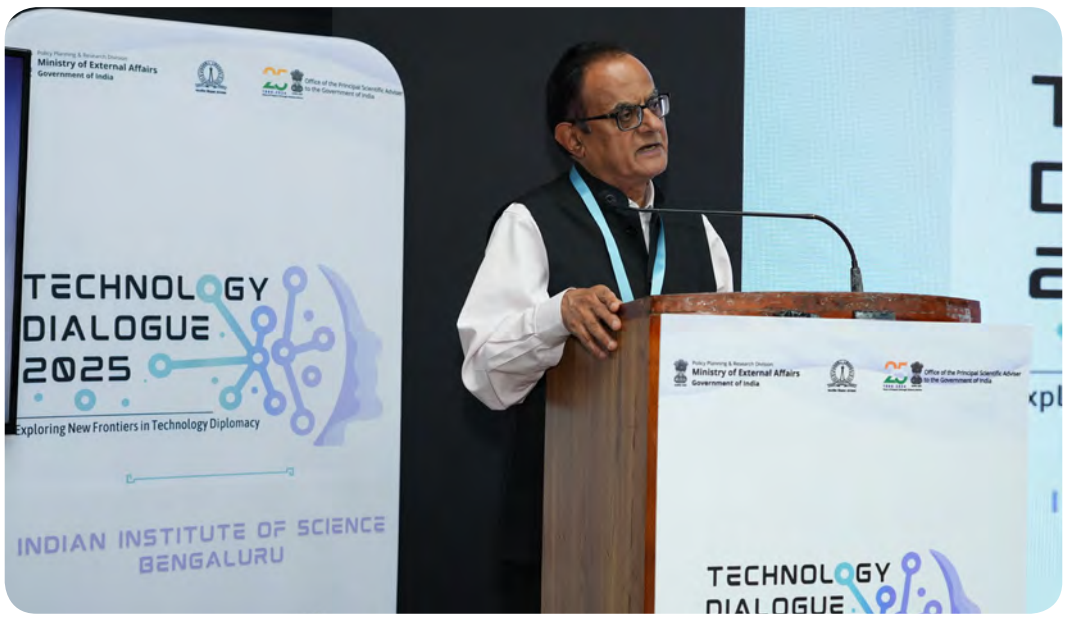
Domestically, the Indian government has launched several initiatives that underscore its commitment to fully utilise the opportunities that emerging technologies present. These include the Anusandhan National Research Foundation (ANRF), the National Quantum Mission (NQM), and the IndiaAI mission. India's space programme has also made significant strides, with the Indian Space Research Organisation (ISRO) achieving notable successes in satellite launches and reusable technologies, further demonstrating the country's growing technological capabilities across multiple domains.

During the recent Technology Dialogue 2025, Prof. G. Rangarajan, Director of the Indian Institute of Science, Bengaluru, emphasised the necessity for "more strategic and sustainable partnerships in emerging technologies among various stakeholder groups internationally." This sentiment reflects the understanding that domestic innovation must be complemented by international collaboration to achieve maximum impact.

Prof. G. Rangarajan, Director, Indian Institute of Science Bengaluru, delivering the inaugural remarks

Framework for International Technology Engagement

For the framework's success, collaborative efforts between India and its partner countries are essential. Prof. Ajay Kumar Sood, Principal Scientific Adviser to the Government of India, highlighted during the dialogue that "synergistic efforts among the stakeholders are essential in ensuring meaningful impact in international technology engagement." He pointed to the Chief Science Advisers' Roundtable, last held in Paris in 2024, as a successful platform that has promoted international collaboration.



Prof. Ajay Kumar Sood, Principal Scientific Adviser to the Government of India, delivering the special address

H.E. Pavan Kapoor, Deputy National Security Adviser (National Security Council Secretariat), Government of India, outlined three key aspects of India's current perspective on international technology engagements:

- Strategic nature - These engagements aim not only to leverage each other's strengths in critical emerging technologies but also to position us as trusted technology partners in these potentially unique and futuristic engagements.

- Involvement of industry and academia - Collaboration in priority technologies flows from the aspirations of our industry and academia, while governmental efforts have provided greater exposure to market opportunities in partner countries.
- Focus on practical applications - The government prioritises outcome-oriented collaborations that promote the co-development and co-production of high-tech products and services to enhance both our technological capabilities and product quality.

H.E. Pavan Kapoor, Deputy National Security Adviser, National Security Council Secretariat, Government of India, delivering the keynote address

Current international technology partnerships exemplify this approach. The India-US TRUST initiative, the Technology Security Initiative (TSI) between India and the United Kingdom, and the India-EU Trade and Technology Council (TTC) are all designed to forge "secure, sustainable and trusted" technology value chains.

As Shri S. Raghuram, Joint Secretary (Policy Planning & Research), Ministry of External Affairs, Government of India, aptly noted, "Technology is an integral part of cooperation, collaboration and contestation among various state and non-state players." This observation underscores the need to ensure that, while focusing on capitalising on rapid technological advancement, our framework should also recognise the significance of inclusive growth.

Shri S. Raghuram, Joint Secretary (Policy Planning & Research), Ministry of External Affairs, Government of India, delivering the inaugural remarks

Leading the "Techade"

The efficacy of India's International Technology Engagement Framework hinges on its capacity to enhance domestic technological capabilities through strategic global partnerships while simultaneously ensuring that technological advancements yield equitable and sustainable benefits to all segments of society. These partnerships, particularly in critical and emerging technologies, are long-term endeavours and would require sustained collaboration and commitment from all stakeholders involved. The government's emphasis on outcome-oriented collaborations and practical applications indicates that India is committed to a long-term vision, distinguishing its initiatives from previous technology partnerships.

As the world enters what Hon'ble Minister Dr Jitendra Singh has termed the "Techade," India's framework for international technology engagement positions the country not just as a participant but as a key architect of the global technological future. Through strategic partnerships, fostering domestic innovation, and a steadfast commitment to inclusive growth, India is charting a course toward technological leadership that promises to reshape the global order in the decades to come.

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Acknowledgements
The contributors extend their sincere gratitude to the distinguished guests and speakers for their valuable contributions.

Guests and Speakers

Welcome Note:
Prof. G.K. Ananthasuresh
Professor and Dean, Division of Mechanical Sciences, Indian Institute of Science Bengaluru

Inaugural Remarks:
Prof. G. Rangarajan
Director, Indian Institute of Science Bengaluru

Shri S. Raghuram
Joint Secretary (Policy Planning & Research), Ministry of External Affairs, Government of India

Special Address:
Dr Kiran Mazumdar-Shaw
Chairperson and Managing Director, Biocon

Special Address:
Prof. Ajay Kumar Sood
Principal Scientific Adviser to the Government of India"

Keynote Address:
Hon'ble Minister Dr Jitendra Singh
Minister of State in the Prime Minister's Office
Minister of State (Independent Charge) of Science & Technology,
Minister of State (Independent Charge) of the Ministry of Earth Sciences,
Minister of State for Space and Atomic Energy,
Minister of State in the Ministry of Personnel, Public Grievance
Minister of State (Independent Charge) for Development of North Eastern Region

H.E. Pavan Kapoor
Deputy National Security Adviser, National Security Council Secretariat, Government of India

Navigating the Tech Wave: India's Technology Partnerships with the World*

The 21st century has witnessed a fundamental transformation in how nations collaborate. Traditional bilateral agreements, which focused on trade and defence, have given way to complex, multifaceted technology partnerships addressing interconnected global challenges. These technological collaborations have become essential because global challenges such as climate change, food security, and public health crises require coordinated international efforts utilising cutting-edge technology solutions. The Technology Dialogue 2025, with its theme 'Exploring New Frontiers in Technology Diplomacy', delved into this evolving landscape.

From Bilateral Exchanges to Complex Ecosystems

International cooperation today bears little resemblance to what existed two decades ago. Modern technology partnerships span multiple domains and involve diverse stakeholders, from government agencies to research institutions and private enterprises. This evolution reflects the growing recognition that technology development and deployment require diverse perspectives and complementary capabilities.

Dr Rama Swami Bansal, Chief Scientist & Head of the International S&T Affairs Directorate at the Council of Scientific and Industrial Research, provided India's perspective on this transformation. She highlighted India's emergence as home to the world's third-largest startup ecosystem, emphasising that India's competitive advantage lies in simultaneously delivering both quality and affordability. India's critical role in the global pharmaceutical supply chain during the recent health crisis demonstrated this capability on a worldwide stage.

The India-UK Technology Security Initiative (TSI) demonstrates how bilateral partnerships increasingly focus on strategic technologies. As H.E. Chandru Iyer, Deputy High Commissioner of the United Kingdom to Karnataka and Kerala, explained, the TSI focuses on key technology sectors, including semiconductors, quantum computing, artificial intelligence, cybersecurity, and biotechnology. He also discussed the collaborative vaccine development efforts between India and the UK during the pandemic, showcasing such partnerships' critical importance. This successful collaboration in healthcare has laid the foundation for expanded cooperation in frontier technologies.

Moving beyond isolated research projects, technology partnerships now aim to build interconnected

* *This article draws insights from the Featured Panel on 'Expanding the Contours of International Engagements for Technology Partnerships,' which was part of the Technology Dialogue 2025.*

innovation ecosystems. Minister Counsellor at the Australian High Commission to India, Carly Partridge, highlighted that research collaborations between India and Australia have reached unprecedented levels, with over 150 active collaborations. The recent announcement of the India-Australia Rapid Innovation and Startup Expansion (RISE) Accelerator further demonstrates how bilateral partnerships are evolving to nurture entrepreneurship and innovation across borders.

Panel Discussion. From left: Dr B. Chagun Basha (Moderator), Dr Soren Tranberg Hansen, H.E. Alfonso Tagliaferri, H.E. Carly Partridge, H.E. Chandru Iyer, Dr Rama Swami Bansal

As climate change emerges as one of humanity's greatest challenges, technology partnerships increasingly focus on sustainable development. The India-Denmark relationship promotes this approach, as Dr Soren Tranberg Hansen, Deputy Head of Mission for Denmark at the Consulate General of Denmark in Bengaluru, explained: "Our green strategic partnership with India represents a new model of international cooperation." Denmark's decision to dedicate two of its seven global innovation centres specifically to the Denmark-India partnership highlights the strategic importance of this collaboration.

If the generation of tangible benefits for society is used as a measure of success for technology partnerships, the India-Italy partnership stands out. Mr Alfonso Tagliaferri, Consul General of Italy in Bengaluru, emphasised this point when discussing the 25-year technological partnership between India and Italy. "Through initiatives like the India-Italy Global Collaboration in Biotech, we're seeing real-world impact in vaccine development and biotechnology," he noted. This long-standing partnership has expanded beyond its initial scope to include energy transition initiatives and major infrastructure projects like the Blue Raman undersea cable, demonstrating how bilateral technology partnerships can evolve and diversify over time.

Beyond Bilateral Partnerships

As technology becomes increasingly intertwined with economics and geopolitics, countries are developing more complex collaborative platforms. The India-US TRUST initiative, the India-European Union Trade and Technology Council (TTC), and the QUAD technology partnerships represent a new generation of bilateral, minilateral and multilateral engagements.

These avenues enable countries to address issues that require coordination beyond bilateral relationships, from setting technology standards to ensuring supply chain resilience and developing regulations for emerging technologies.

The future promises even deeper integration of technology into diplomatic relationships. Upcoming initiatives, such as the India-France Year of Innovation (2026) and the India-Spain Year of Culture, Tourism and AI (2026), signal a future where international technology partnerships become central to foreign policy.

These partnerships are no longer optional add-ons to diplomatic relationships but essential components of strategic engagement in a world where technological leadership increasingly determines economic prosperity and geopolitical influence.

Collaboration as the Only Path Forward

The extensive discussions during the Technology Dialogue 2025 made one thing abundantly clear: no country can succeed in isolation in addressing global challenges through technology. The future belongs to nations that can build bridges, share knowledge, and innovate together.

As technology continues to advance at an unprecedented pace, collaboration isn't merely one option among many—it has become the only viable path forward for solving our shared global challenges. The countries that master the art of technology partnerships will be best positioned to thrive in this new era of innovation-driven development.

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Speakers

Dr Rama Swami Bansal
Chief Scientist & Head, International S&T Affairs Directorate, Council of Scientific and Industrial Research (CSIR), India

H.E. Chandru Iyer
His Majesty's Deputy Trade Commissioner for Investment for South Asia Deputy High Commissioner of the United Kingdom to Karnataka and Kerala

H.E. Carly Partridge
Minister Counsellor, Australian High Commission to India

H.E. Alfonso Tagliaferri
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Dr Soren Tranberg Hansen
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Moderated by:
Dr B. Chagun Basha
Chief Policy Adviser, Policy Analytics and Insights Unit, Office of the Principal Scientific Adviser to the Government of India

India's Technological Transformation through Digital, Industrial and Energy Transitions*

India's technology landscape is currently being shaped by three critical transitions: digital, industrial and energy. Policy decisions addressing these transitions have profound implications for India's economic stability, national security, and international standing, as highlighted by Special Secretary Shri Periasamy Kumaran in his keynote address during the Technology Dialogue 2025. These transitions are influenced by changing global technology paradigms and dynamic geopolitical realities.

India is continuously advancing technology deployment to drive growth and development. The country is recording notable success in various sectors. The rise of a robust startup ecosystem has established India as the third-largest startup ecosystem in the world (PIB Report, Ministry of Commerce and Industry). By 2024, India has recorded over 1.59 lakh registered startups, a significant increase from around 500 in 2016. This rapid growth has also resulted in the establishment of over 100 unicorns. The startup ecosystem is spread across various sectors, including fintech, edtech, health tech, and deep tech, significantly contributing to India's digital economy, which is estimated to hit $1 trillion by 2030 (KPMG).

Efforts to build digital public infrastructure have transformed the delivery of services and financial inclusion across India's varied demographic spectrum. The Unified Payments Interface (UPI) handles more than 16 billion transactions every month, amounting to $1.5 trillion annually. Aadhaar, the world's largest biometric identification system, now covers over 1.4 billion citizens. The CoWIN platform effectively managed over 2 billion COVID-19 vaccinations. The DigiLocker service, with over 490 million users, provides secure access to digital documents.

India's technological capabilities extend beyond its borders through strategic global partnerships. The country has created seminal technology cooperation frameworks with leading global powers. The Technology Security Initiative with the UK prioritises cybersecurity, new technologies, and defence innovation, including collaborative research initiatives. The India-US Initiative on Critical and Emerging Technologies (iCET) focuses on defence innovation, semiconductor supply chains, and artificial intelligence, with over $10 billion invested in semiconductor production. The India-EU Trade and Technology Council is dealing with clean energy technology, digital governance, and strategic technology partnerships, including joint ventures in quantum computing and green hydrogen.

On the multilateral front, India's entry into the QUAD initiative has played a pivotal role in shaping world technology governance and supply chain security. QUAD endeavours include a semiconductor supply chain project, and artificial intelligence, with over $10 billion invested in semiconductor production. The

* *The article draws insights from the keynote address titled 'Technology and Development Partnerships of India,' which was part of the Technology Dialogue 2025.*

India-EU Trade and Technology Council is dealing with clean energy technology, digital governance, and strategic technology partnerships, including joint ventures in quantum computing and green hydrogen.

Shri Periasamy Kumaran, Special Secretary (ER & DPA), Ministry of External Affairs, Government of India

On the multilateral front, India's entry into the QUAD initiative has played a pivotal role in shaping world technology governance and supply chain security. QUAD endeavours include a semiconductor supply chain project, 5G deployment and diversification, and horizon scanning for frontier technologies. The QUAD Fellowship scheme sponsors 100 STEM graduate students from member states annually. The nation's pledge to capacity building in technology is best reflected through the Indian Technical and Economic Cooperation (ITEC) programme, which has trained over 200,000 officials from 160 nations, establishing India as a knowledge centre for digital transformation in the Global South.

Inclusive development continues to be at the core of India's technology deployment policy. The Production Linked Incentive (PLI) scheme, with $26 billion across 14 sectors, has attracted over $20 billion of investments in electronics manufacturing alone. The indigenous 5G technology development via the 5Gi standard will reduce deployment costs by 40%. Mass digital literacy initiatives under the Pradhan Mantri Gramin Digital Saksharta Abhiyan (PMGDISHA) have covered more than 40 million rural citizens, intending to reach 60 million by 2025. BharatNet, a project aimed at bridging the digital rural-urban divide, has brought high-speed internet to more than 150,000 Gram panchayats.

As global supply chains and strategic mineral resources become paramount concerns in geopolitical relations, India's international technology partnerships increasingly incorporate technology transfer and capacity-building components in the trade agreements to address these vulnerabilities. The India-Japan Digital Partnership focuses on 5G, AI, and IoT technologies, with $5 billion allocated for collaborative projects. The partnership with Australia centres on critical minerals and rare earths, including a $100 million stake in critical minerals processing. These strategic partnerships help India anchor its position in international value chains and build indigenous capabilities in emerging technologies such as quantum computing, artificial intelligence, and critical materials.

India has emerged as a significant player in space technology, demonstrating remarkable technological capabilities through a series of achievements. The Mars Orbiter Mission was India's first interplanetary mission, marking the country's role in deep space exploration. Building on this, the Chandrayaan-3 lunar

expedition, completed on a budget of less than $75 million, proved to be an economical innovation in space exploration. Moreover, India's indigenous satellite launch capabilities, developed by ISRO, have placed India alongside select space-faring nations. The government's strategic decision to commercialise space activities via IN-SPACe has drawn over 100 space-tech startups, with private sector investments in the space sector exceeding $2 billion. Additionally, India has established itself as a reliable commercial partner in the global space economy, earning over $400 million in foreign exchange from commercial satellite launches for 34 nations.

The integration of climate factors and technology into foreign policy and geopolitical interventions marks a new chapter in India's international policy engagement. India aims to install 500 GW of renewable energy capacity by 2030, reflecting the country's commitment to clean energy and technological innovation. The International Solar Alliance (ISA), founded by India and comprising 110 members, has facilitated more than $1 billion in financing for solar power initiatives. India's green hydrogen mission aims to make 5 million tonnes annually by 2030, creating a new energy economy worth $12 billion.

Through these holistic initiatives and collaborations, India is revolutionising its domestic technology ecosystem and becoming a key driver of global technological development and deployment. The country's strategy for harnessing technology for inclusive growth while ensuring strategic autonomy and promoting global cooperation places it in a distinct position in the new world technological order. Its regulatory system strikes a balance between innovation and ethics, as demonstrated by the Digital Personal Data Protection Act 2023 and the National Data Governance Framework Policy, raising the bar for responsible technology rollout.

As India stands at the crossroads of these revolutionary changes, its path represents more than mere technological progress. It is a model of inclusive innovation that balances rapid progress with social responsibility. India is increasingly playing a central role in global technology governance, with a vibrant innovation ecosystem and a strong commitment to sustainable development. This positions India as not just a participant but a leading architect of the world's technological future. The convergence of digital excellence, industrial innovation, and clean energy solutions reflects India's integrated vision for technological preeminence in the 21st century.

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The contributor extends her sincere gratitude to Shri Kumaran for his invaluable contributions.

Keynote Address

Shri Periasamy Kumaran
Special Secretary (ER & DPA)
Ministry of External Affairs, Government of India

Shifting Landscape of Indian Space Sector*

From having an infant space programme in the 1960s, India, as a space-faring nation, has grown by leaps and bounds. For over six decades, the Indian Space Research Organisation (ISRO) has been at the forefront of India's space activities, achieving remarkable milestones in satellite development and launch capabilities. India's space sector is now undergoing a dynamic shift with the opening of the private sector. The panel discussion during the Technology Dialogue 2025 on "India's Space Sector: A Gateway for Global Investment and Peaceful Exploration," featuring ex-ISRO Chairman and Ex-Secretary of Department of Space Dr S. Somanath and Chief Technology Officer of Axiom Space (APAC region), Dr Koichi Wakata, served as a timely reminder of India's growing potential to be the leading option for foreign investments and a potential collaborator across all segments of the global space industry.

Shifting Landscape of New Space

The modern space age, also considered an entrepreneurial space age, has been developing for years. Historically, space exploration was the domain of a select few nations with advanced infrastructure and government-backed space agencies. In recent years, the cost of accessing space has drastically reduced with the advent of private companies. Companies such as SpaceX, Blue Origin, and OneWeb have demonstrated how private organisations can capitalise on commercial opportunities in this new space era. Countries worldwide are witnessing an increase in space startups, private investments, and commercial missions, all aimed at making space more accessible and economically viable. This disruption of the market has also created opportunities for India to strengthen its position within the global landscape of space technology and exploration.

Future of the Indian Space Economy

ISRO's huge successes stemming from missions catering to national requirements such as EDUSAT, RISAT, and more recently, Mangalyaan and Chandrayaan missions, as well as budget-friendly satellite launches, have firmly established India as a credible space-faring nation. As Dr Somanath mentioned, the space sector, traditionally led by ISRO, is now being reshaped through various government initiatives, such as the Indian National Space Promotion and Authorization Center (IN-SPACe). With over 200 space startups in India, the country is witnessing an entrepreneurial boom. Companies such as Skyroot

* *This article draws insights from the Dialogue titled 'India's Space Sector: A Gateway for Global Investment and Peaceful Exploration,' which was part of the Technology Dialogue 2025.*

Dialogue. From left: Ms Shweta Rajpal Kohli (Facilitator), Dr S. Somanath, Dr Koichi Wakata

Aerospace, Agnikul Cosmos, and Pixxel Space are at the forefront of this growth, developing cutting-edge technologies to create indigenous solutions and attract global investment.

Government policies and regulatory reforms have played a crucial role in this shift. The Indian Space Policy 2023 marks a critical step forward, enabling greater private-sector participation and creating a competitive ecosystem in space tech. Along with the Norms, Guidelines and Procedures, IN-SPACe has provided a structured framework for private sector engagement. India has also recently amended its foreign direct investment (FDI) policy to allow up to 100% FDI in the space sector and has committed to systemic reforms to facilitate the participation of private players. These reforms seek to liberalise FDI policy provisions in the space sector by prescribing liberalised entry routes. They also provide clarity for FDI in satellites, launch vehicles, and associated systems or subsystems, as well as the creation of spaceports for launching and receiving spacecraft and manufacturing space-related components and systems.

At the same time, defence and strategic space investments are increasing with the establishment of the Defence Space Agency (DSA) and the MoD-iDEX DefSpace Challenges. These initiatives highlight India's focus on secure communications, space-based surveillance, and counter-space capabilities. Space remains an emerging sector of massive potential for commercialisation, with strong private sector interest in India.

India has the potential to become a global hub for space innovation, but private investment in research and development facilities remains insufficient. Dr Somanath underlined the need for increased spending on training and research facilities, especially in critical and emerging technologies like semiconductors, artificial intelligence (AI) and deep tech – areas increasingly intersecting with space tech and holding immense potential on their own.

Deep Tech in Space and the Future of Space Innovation

Dr Wakata's presentation highlighted the role of technological convergence in shaping the space industry. AI, quantum computing, robotics, and biotechnology are now being integrated into space systems. The rapid advancement of deep technologies is poised to transform the space industry, driving innovation across multiple domains, including satellite technology, space manufacturing, human spaceflight, and in-situ resource utilisation.

AI-driven autonomy is optimising satellite operations and deep-space missions, reducing the reliance on Earth-based control. Quantum technologies, particularly Quantum Key Distribution (QKD), are enabling

ultra-secure satellite communications and enhancing navigation accuracy. Advancements in space-grade semiconductors and edge computing are improving the efficiency of space missions. Space biotechnology is opening new frontiers in drug development, regenerative medicine, and bioprinting—fields crucial for long-duration human spaceflight. Propulsion technologies are also evolving rapidly, with innovations such as Nuclear Thermal Propulsion (NTP). Strategically investing in Deep Tech is key to driving the future phase of space exploration.

Call for Global Collaboration and the Road Ahead

India stands at a critical juncture in space technology and exploration. The government has set the stage for progress through recent policy reforms, but sustained growth will require bold investments, a risk-taking appetite from entrepreneurs and a relentless focus on innovation. Dr Somanath aptly noted that while the opportunities are vast, only those willing to venture beyond traditional realms will succeed. India can carve out a niche for itself in space innovations beyond traditional satellite launches, especially in deep-tech areas such as space-based solar power, in-orbit manufacturing, lunar economy and deep-space exploration. During the Dialogue, Dr Wakata also laid emphasis on deep-tech innovations in space and encouraged startups to take on end-to-end responsibilities and expand their scope beyond specialised components.

India aims to have a more sustained presence in space, expanding its human-spaceflight capabilities with a space station of its own in the coming decade. International engagements with global space companies like Axiom Space and government space agencies like NASA provide unique opportunities and experience building, such as participation in International Space Station missions, the recent example being Group Captain Shubhanshu Shukla from India aboard the Axiom mission. India's vision of establishing the Bharatiya Antariksha Station highlights the immense possibilities ahead. Realising these goals will need highly coordinated efforts from various stakeholders. Beyond scientific collaborations, space security and governance are becoming critical priorities. With the increasing risk of space debris and orbital congestion, global Space Traffic Management (STM) coordination is essential to ensure long-term sustainability. Strengthening bilateral and multilateral agreements will unlock doors for technology and knowledge sharing and strengthen India's position in the global space tech value chain. With a future-ready and collaborative framework in place, India can position itself as a key player in the rapidly evolving space ecosystem.

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Policy Brief: Building India's Quantum Future through Synergistic Collaborations*

Introduction

As quantum technology shifts from theoretical concepts to practical applications, nations worldwide are competing for leadership in this transformative domain. India has reached a defining point in its quantum journey with the National Quantum Mission (NQM), marking a strong national commitment to quantum development. Based on the panel discussion "Fostering Collaboration for Quantum Revolution" during the Technology Dialogue 2025, this policy brief explores India's role within the international quantum ecosystem. It highlights opportunities and challenges towards building quantum capacities in India. As we move into 2025, the International Year of Quantum Science and Technology, the timing is particularly relevant for considering strategic responses to quantum advancements through collaborative mechanisms.

What is Quantum Technology?

Quantum technology is based on quantum mechanics – the principles governing the behaviour of matter and energy at the atomic and subatomic levels. It leverages quantum phenomena like superposition (where particles exist in multiple states simultaneously) and entanglement (where particles remain interconnected regardless of distance) to enable computational power and security systems previously deemed unattainable. The year 2025 marks the centenary of quantum mechanics, a milestone recognised by the United Nations, which declared it the International Year of Quantum Science and Technology (IYQ). This resonates with quantum research's impressive progress and growing technological applications.

Over the past three years, quantum technology has evolved from solely scientific endeavours to an industry with nascent commercial applications. The quantum sector is undergoing a transition similar to the advent of high-performance computers in the 1950s. Today error correction is feasible for certain tasks but not applicable across all quantum computing challenges. The international focus has moved from the quest for quantum supremacy (theoretical dominance) to quantum utility (practicality). This is especially evident in quantum communication technologies, where advances in Quantum Key Distribution (QKD)—a technology that enables the creation and distribution of secure keys for data encryption during transmission—have shown how transparency in protocols can be compatible with secure implementation.

* *This policy brief draws insights from the panel discussion titled 'Fostering Collaboration for Quantum Revolution,' which was part of the Technology Dialogue 2025.*

Panel Discussion. From left: Mr Luke Preskey (Moderator), Prof. Urbasi Sinha, Prof. Ajay Kumar Sood, Dr Amith Singhee, Prof. Andrew White

National Quantum Mission (NQM)

NQM, launched by the Government of India and spearheaded by the Department of Science and Technology (DST), is a comprehensive initiative (2023–2031) to foster scientific and industrial R&D, innovation and industry participation in quantum technologies. The mission will establish four Thematic Hubs (T-Hubs) at leading academic and national R&D institutions, focusing on:

1. Quantum Computing
2. Quantum Communication
3. Quantum Sensing & Metrology
4. Quantum Materials & Devices

These hubs will facilitate basic and applied research, nurture talent and drive technological advancements in their respective domain.

India's Progress in Quantum Technology

India's quantum strategy takes a multistakeholder approach, integrating efforts from academia, industry, and research institutions. Key focus areas include:

- Human Resource Development: The DST, in collaboration with the All India Council for Technical Education (AICTE), has announced a dedicated curriculum at the undergraduate level to build a skilled quantum workforce[1].
- Alignment with National Priorities: The mission supports broader initiatives such as digital India, Make in India, Skill India and Stand-up India, Start-up India, Self-reliant India and the Sustainable Development Goals (SDG)[2].
- Public-Private Partnerships: India is fostering collaboration between startups, academia, and industry to accelerate quantum research and development.
- International Collaboration: India actively engages in bilateral and multilateral partnerships to strengthen its quantum ecosystem. Recently, Indian Science and Technology Minister Jitendra Singh invited Israeli startups to collaborate under India's NQM, particularly in advancing quantum computing, encryption, and sensing technologies[3].

- Support to startups: Eight startups have been selected under NQM and the National Mission on Interdisciplinary Cyber-Physical Systems to drive innovation in quantum computing, communication, sensing, and materials[4].

To ensure the protection and commercial viability of quantum innovations, India is implementing frameworks under the draft Science, Technology, and Innovation Policy 2020. Substantial emphasis has been put on capitalising on India's techno-savvy young generation with special training schemes and academia-industry collaboration through initiatives like SPARC (Scheme for Promotion of Academic and Research Collaboration), IMPRINT (IMPacting Research INnovation and Technology), UAY (Uchhatar Avishkar Yojana), and research parks. This aims to bridge academia-industry collaboration and foster technology commercialisation.

SWOT Analysis: India's Quantum Technology Landscape:

STRENGTHS	**WEAKNESSES**
• Strong government support through NQM. • Integration with national initiatives like Digital India, Make in India, skill India and StartUp India • Focus on technological self-reliance and global competitiveness • Support for R&D, innovation and startup incubation	• Limited market demand for sustaining long-term quantum development • Lack of required infrastructure • Skill gap • Lack of a comprehensive policy framework for academic entrepreneurship
OPPORTUNITIES	**THREATS**
• Global collaboration, especially in global quantum standards and research • Industry-academia partnerships for knowledge transfer and commercialisation • Private sector participation in advancing quantum applications • Growing tech-driven youth population to build future talent • Strategic positioning of India as a global leader in technology • Real-world applications in health care, fintech, and material science • Open source initiatives and collaborative ecosystems • Development of India's technology diplomacy through the quantum sector	• Technology embargoes restricting international collaboration • Rapidly evolving field– requires continuous adaptation, policy updates, and investments to stay competitive • Geopolitical tensions and competition for dominance • Risk of global standards being dominated by a few nations • Extensive funding requirements • "Harvest now, decrypt later" security threats, particularly in fintech and medical fields • Competition for talent in the global quantum ecosystem– "brain drain" • Ethical challenges

Key Action Points for Quantum Development:

1. **Building Collaborative Research Ecosystems**
   India should break the institutional silos and build vibrant research ecosystems. It should draw from exemplary models such as the Australian Centers of Excellence to set up long-term collaborative frameworks (7+ years), integrating complementary strengths from academia, industry, and government labs.
2. **Strengthening Industry-Academia Technology Translation**
   The disconnect between theoretical quantum research and commercial use is one of India's greatest

challenges. To overcome this, specialised technology translation centres can be set up at the boundary between universities and industry. These centres would help to:

a. Develop standardised intellectual property-sharing frameworks that reward both academic innovation and commercialisation
b. Set up "entrepreneur-in-residence" programmes where industry experts work alongside academic researchers
c. Establish prototype-to-product pathways with shared technical infrastructure and market knowledge
d. Offer expert mentorship to quantum startups facing technical and business issues

3. **Strategic International Partnerships**

India's quantum future demands a skillfully balanced approach to international engagement that strikes the right balance between openness and strategic autonomy. Instead of trying to develop all quantum capabilities indigenously, India can strive to:

a. Form bilateral R&D collaborations in non-sensitive quantum application domains with advanced quantum countries
b. Engage proactively in global quantum standard-setting initiatives to make India's needs heard
c. Develop targeted exchange programs for researchers in strategic quantum areas
d. Establish joint testbeds for quantum communication technologies with trusted foreign partners

This strategy enables India to leverage international quantum developments while developing local capabilities in strategic areas of interest, especially quantum-secure communications and sensing technology.

4. **Dynamic Policy Frameworks and Governance**

Conventional technology governance mechanisms are not agile enough for the fast-changing quantum environment. India needs adaptive policy frameworks that keep pace with technological advancements while offering stability for long-term investments. These could include:

a. Creation of a multistakeholder Quantum Advisory Council comprising representatives from academia, industry, and civil society
b. Periodic review cycles of policy aligned with quantum technology development cycles
c. Establishment of dedicated regulatory sandboxes to test quantum technologies that have possible dual-use purposes
d. Equilibrium frameworks that safeguard intellectual property while facilitating knowledge sharing in pre-competitive research domains

Way Forward

The quantum revolution presents both unprecedented opportunities and complex challenges that demand a collaborative effort from multiple stakeholders. Positioning India in the global quantum landscape will depend on several key factors: strengthening domestic R&D and innovation ecosystem, promoting domestic and international collaborations while ensuring strategic autonomy, and human resource development.

The path to quantum leadership needs a delicate balance between open collaboration and strategic interests. Maintaining a strong balance between global integration and technological self-reliance is also critical. India can establish itself as a key actor in the global quantum revolution by adopting a multi-dimensional approach, including bilateral, minilateral, and multilateral collaborations across government, the private sector, and academia. This will not only enhance India's technological prowess but also strengthen its position in global technology diplomacy, contributing to digital transformation and self-reliance in emerging technologies.

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From AI for All to AI for the World: How India is shaping the Future of Artificial Intelligence*

AI's rapid advancements are transforming industries and economies around the world, with the technology projected to contribute a staggering $15.7 trillion to the global economy by 2030[1]. India is determined not to be left behind. Experts estimate that AI could add up to $957 billion to India's economy by 2035 – roughly 15% of its current GDP[2]. Previously regarded as a technology follower, India is now positioning itself as an emerging AI powerhouse. It has climbed 19 places in the global AI readiness index, ranking 32nd out of 181 countries[3]. At the Technology Dialogue 2025, panellists from the "Accelerating Artificial Intelligence (AI) Innovation" session emphasised that India's AI strategy extends beyond economic targets. It focuses on leveraging AI to solve societal challenges, shaping progressive policies, and fostering international collaboration. While AI promises prosperity, its power must be guided by purpose and principles. With a clear vision and strategic interventions, India is crafting a narrative of "AI for All," aiming to drive domestic growth while also advocating for responsible AI diplomacy abroad.

India's AI Vision and Policy Landscape

India's AI journey formally took shape in 2018 with the "National Strategy for Artificial Intelligence (NSAI)", built around the principle of "AI for All." This vision recognises AI as a transformative tool to tackle social challenges in areas like agriculture, healthcare, and education, extending beyond economic gains[4]. The strategy cemented the idea that AI should empower every citizen and enhance public welfare. To translate this vision into action, the IndiaAI Mission was approved in 2024 with a budget of ₹10,300 crore (≈$1.3 billion) over five years[5]. A key initiative under this mission is the creation of a massive AI computing infrastructure: a high-end national AI cloud equipped with over 18,000 Graphics Processing Units (GPUs) to support researchers and startups[5]. Once fully online, this will be one of the world's largest AI supercomputing facilities – nearly nine times the capacity used to train the open-source AI model DeepSeek and about two-thirds of the computing power behind ChatGPT[5]. While such computing capabilities were traditionally dominated by tech giants, India aims to democratise access by making them a public resource. Already, 10,000 GPUs have been deployed in the first phase, and an open GPU marketplace allows startups and students to rent computing power at subsidised rates (₹100 per hour, compared to $2.5–$3 globally), ensuring broader accessibility.

Building indigenous "AI" capacity is another priority. The government has announced plans to develop India's own AI chips and GPUs within 3-5 years, reducing reliance on imports and complementing a

* *This policy brief draws insights from the panel discussion titled 'Accelerating Artificial Intelligence (AI) Innovation,' which was part of the Technology Dialogue 2025.*

Panel Discussion. From left: Prof. Chiranjib Bhattacharyya (Moderator), H.E. Arthur Barichard, Shri S. Krishnan, Ms Laxmi Shenoy, Dr Leah Junck, Shri Biswajit Das

broader semiconductor mission. Multiple Centres of Excellence (CoEs)[6] have been established to drive AI research and domain-specific innovation, including three in New Delhi and a recently announced CoE focussed on AI in Education[5]. To ensure a steady talent pipeline, National CoEs for Skilling in AI are being launched in partnership with global industry leaders, following the principle of "Make for India, Make for the World." India's AI regulatory approach has remained pragmatic, balancing innovation with risk mitigation and data privacy. Policies and frameworks are designed to foster responsible AI development while supporting India's broader vision of becoming a "Viksit Bharat" by 2047.

Global AI Collaborations and Diplomacy

India's AI aspirations extend beyond its borders, positioning the country as a bridge-builder in global AI governance. At Technology Dialogue 2025, discussions highlighted India's proactive engagement in AI diplomacy through multilateral forums and strategic partnerships, reinforcing its role in shaping AI development and regulation at the international level.

One prominent example is India's leadership in the Global Partnership on Artificial Intelligence GPAI)—a coalition of 29 nations and the EU dedicated to responsible AI. India joined GPAI as a founding member in 2020[7] and became Chair of its governing council in November 2022[8]. In 2023, India hosted GPAI's annual summit in New Delhi[9], advocating for ethical AI governance and proposing initiatives such as an AI-origin "watermark" to label AI-generated content[10]. This active participation has strengthened India's reputation as a consensus-builder in global AI policymaking.

India's leadership was further solidified when it co-chaired the AI Action Summit in Paris in February 2025[11] alongside France. This summit broadened the global AI dialogue beyond risk management, highlighting AI's potential to drive innovation and inclusion. Recognising India's growing leadership,

international stakeholders have increasingly viewed it as a key player in diversifying AI governance, particularly in representing the Global South and promoting AI access rooted in democratic values, cultural diversity, and equitable technology development.

Bilateral partnerships are another key facet of India's AI diplomacy. The India–France Roadmap on Artificial Intelligence, launched in February 2025 focuses on jointly developing safe, open, secure and trustworthy AI systems[12]. India has also collaborated with the United States through the Initiative on Critical and Emerging Technologies (iCET)[13] and engaged in AI discussions with the United Kingdom under a broader tech partnership.

At multilateral forums like the G20 Presidency in 2023, India placed digital public infrastructure and AI governance at the forefront of global discussions. The G20 New Delhi Leaders' Declaration acknowledged AI's rapid progress and reaffirmed a commitment to a pro-innovation, responsible AI framework aligned with G20 AI Principles adapted from OECD guidelines[14]. Later, at the Paris AI Summit (2023), India joined 57 countries (including France, Canada, and China) in signing the Joint Statement on Inclusive and Sustainable AI, pledging to advance AI that "is human rights-based, human-centric, ethical, safe and secure.[15]"

These efforts establish India as a rising diplomatic force in AI, aligning domestic AI-driven development with a global vision of cooperative governance. This approach, often described as a "techade of partnerships", reflects India's commitment to sharing its digital innovations while actively contributing to international AI policymaking. By championing inclusive AI governance, India seeks to ensure that the next phase of AI evolution is not dictated by a select few but shaped through collective global leadership.

The Path Forward

As the Technology Dialogue 2025 discussion drew to a close, there was a palpable sense of both achievement and urgency. While India has made significant strides in AI innovation and governance, much remains to be done to realise the promise of AI for its 1.4 billion people and to shape the international AI landscape. The panel outlined key recommendations for India's AI roadmap in the coming decade:

- **Invest in Research & Infrastructure**: Continue strengthening the fundamental pillars of AI – data, research, and computation. Expand AI compute infrastructure beyond the initial 18,000 GPUs, possibly setting up multiple regional AI supercomputing centres to ensure nationwide access.
- **Enable AI for Everyone – Inclusion and Skilling:** To truly achieve "AI for All," India must ensure that the benefits of AI reach every section of society. This involves mega-scale skilling programmes to train workers in AI skills, from basic AI literacy for office workers to advanced ML training for engineers. By 2030, AI proficiency should be as commonplace as basic computer skills are today.
- **Strengthen Ethical Governance and Regulation**: As India's AI adoption deepens, it will be important to formalise aspects of AI governance. India should formalise AI governance through a co-regulation model involving government, industry, and civil society to build trust in AI.
- **Foster Global Collaboration and Leadership**: India must champion a collaborative and inclusive vision for AI. By sharing best practices, co-developing solutions, and advocating for the interests of the Global South in AI regulation, India can ensure the global AI revolution is more equitable.
- **Adapt and Iterate**: Given AI's rapid evolution, India should establish a high-level AI Task Force or Commission to continuously evaluate advancements and recommend policy updates.

The narrative that emerged from the Technology Dialogue 2025 was one of optimistic realism: an optimism that AI can drive inclusive, innovative, and globally influential India, tempered by the realism

that careful stewardship is needed. India's "AI for All" vision and active global engagement offer a compelling model for nations navigating the AI age. The coming years will test India's ability to implement its ambitious plans. As the panel concluded, the story of India and AI is ultimately about empowerment and leadership. The world will be watching as India writes this next chapter of the digital age in its own unique and democratic way.

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Advancing India's Leadership in Sustainable Global Biotechnology*

The days when "biotech" meant complicated science locked away in laboratories are long gone. Today, India's bioeconomy is transforming industries, from energy and healthcare to agriculture and manufacturing. The sector has witnessed remarkable growth, from $10 billion in 2014 to an impressive $130 billion by 2024[1]. India's innovations are making a global impact, benefitting both developing and developed nations by addressing critical challenges such as drug pricing. Through strategic international partnerships, India's potential is being translated into worldwide solutions.

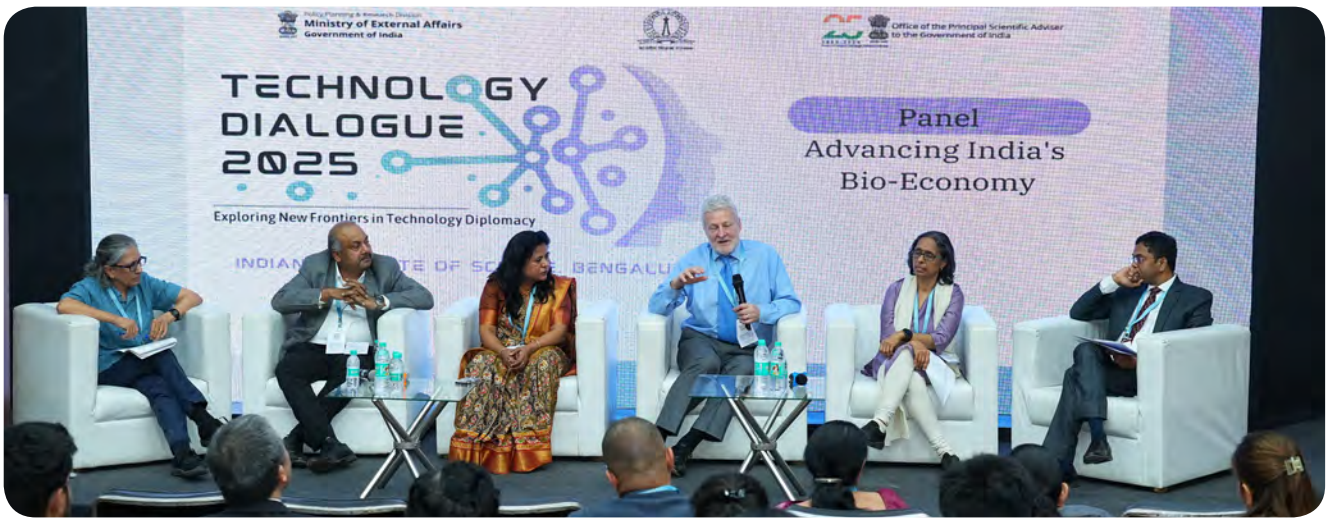
In 2024, India launched the BioE3 policy (Biotechnology for Economy, Environment and Economy), which aims to expedite the development of bio-based products and technologies. This will be achieved through establishing BioEnablers, encompassing Bio-AI Hubs, Biofoundries, and Biomanufacturing Hubs across the country, ultimately promoting commercialisation within the sector.

India's ambitious blueprint for biotech innovation is changing the game. This comprehensive policy not only fosters economic growth but also creates opportunities in unexpected regions, particularly smaller cities and towns where local talent and resources are fuelling the rise of new biotech enterprises. In 2023 alone, India witnessed the establishment of 1,776 new biotech start-ups, bringing the total to 8,531[2]. These figures represent more than statistics—they are narratives of grassroots innovation.

India gained global recognition during the COVID-19 pandemic for its rapid vaccine production. From a global perspective, new technologies such as CRISPR-Cas9 and mRNA will shape the future of medicine.

> ***The Global stage is being set for India. India is represented at the table and is playing its part and is doing more as time goes on.***
>
> **Mr Peter Bains, Group CEO, Biocon Group**

* *This article draws insights from the panel discussion titled 'Advancing India's Bioeconomy,' which was part of the Technology Dialogue 2025.*



Panel Discussion. From left: Prof. Gayatri Saberwal (Moderator), Shri Krishna Mohan Puvvada, Dr Alka Sharma, Mr Peter Bains, Prof. Usha Vijayraghavan, Dr Bhuvnesh Shrivastava

Building on its momentum in health innovation, India now possesses the technology, ecosystem, and capital to drive innovations across sectors. The country is actively engaging in technology diplomacy on the global stage through projects like the Initiative for Critical and Emerging Technologies (iCET) with the United States and the Trade and Technology Council (TTC) with Europe.

A major challenge remains bridging the gap between academic research and market applications. This requires structured pathways that can effectively translate laboratory discoveries into commercial solutions. Most academic & research institutions typically reach a Technology Readiness Level (TRL) of 4. However, industry collaborations generally commence at TRL 7-8, necessitating efforts to bridge this gap and ensure industry-ready research. Under the BioE3 policy, Biofoundries focus on TRL 5-7, while Biomanufacturing Hubs aim to advance technologies from TRL 3-5 to TRL 9 (pre-commercialisation), as highlighted by Dr Alka Sharma, Additional Secretary/ Scientist 'H', Department of Biotechnology (DBT), Government of India.

Establishing Biofoundries and Biomanufacturing units within academic institutions can help bridge this divide. Industry-academia collaboration is the key to detecting and filling innovation gaps and aligning research with the BioE3 policy. Institutions such as the Foundation for Science Innovation and Development (FSID) at IISc, cited by Prof. Usha Vijayraghavan, Dean, Biological Sciences Division, IISc, play a pivotal role in translating research into viable applications by facilitating collaboration between academia and industry.

India's biotechnology strategy is structured around four key pillars: capacity building, innovation ecosystem development, product commercialisation, and balanced research. One of the significant aspects of this strategy is creating Biofoundries in tier-3 and tier-4 cities, thereby decentralising biotechnology innovation beyond metropolitan areas. These centres are fostering value-based manufacturing and industrial cooperation on a broader scale.

International partnerships are at the forefront of the pharmaceutical industry's change, with U.S.-India cooperation serving as a prime example. These collaborations operate at multiple levels—from bilateral initiatives to multilateral engagements such as QUAD and specialised platforms like the India-U.S. Trade Policy Forum (TPF). The pragmatic effect of this partnership is evident in India's recent tax deductions on life-saving medicines, including cancer drugs. As Dr Bhuvnesh Shrivastava, Director (Healthcare), US-India Strategic Partnership Forum, discussed, the India-U.S. partnership is mutually beneficial: India offers cheap generic medicines, while the U.S. provides cutting-edge therapeutic technologies and medical equipment. With more than 200 FDA-approved facilities, India has emerged as a trustworthy manufacturing partner, although it remains reliant on U.S. technology for advanced medical equipment.

Furthermore, India's open regulatory system strengthens its status as a desirable collaboration partner. In addition, India is geographically well-placed to benefit from changing geopolitical trends, especially as China's position in manufacturing and clinical trials is changing. Effective R&D and manufacturing collaborations with the Gulf Cooperation Council (GCC) nations have improved India's global standing in the pharmaceutical industry.

Sustainability is driving transformation in India's biotechnology sector. According to the World Economic Forum, "Policies in support of biological production of everyday chemicals and energy are gaining momentum, reducing greenhouse gas (GHG) emissions by up to 90%[3]." India is actively capitalising on these opportunities through several interconnected approaches. A major focus is converting biodegradable waste into energy, alongside advancements in bio-plastics. Shri Krishna Mohan Puvvada, Senior Vice President, Planetary Health and Regional President, MEIA, highlighted that India's abundant sugar resources make it the potential leader in bio-plastics production from sugar-derived derivatives. This extends to innovations such as polyethylene terephthalate (PET) degradation by fermentation processes underscoring India's push towards creating a sustainable, circular bioeconomy.

The sector is also pushing boundaries in sustainable manufacturing, moving beyond traditional production methods. The BioE3 policy prioritises value-based, low-carbon manufacturing processes[4] across biotechnology sectors. For example, Novozymes use enzymatic carbon capture, a cleaner and more cost-effective alternative to traditional carbon capture techniques, as documented in The Novozymes Report (2022)[5]. This integration of academic research with industrial applications is creating new paradigms for sustainable production.

India has set an ambitious target of expanding its bioeconomy to $300 billion by 2030, a significant leap from its current 3% share in the global market. This trajectory represents India's evolution from a generic drug producer to a high-value biotechnology solutions innovator, positioning the country as an emerging biotechnology and green manufacturing leader.

As Prof. Gayatri, Dean, Institute of Bioinformatics and Applied Biotechnology, rightly observed, 'Knowledge of today will be suddenly discovered as the tool for technology in the future.' This insight reflects India's strategic vision of using its strengths in healthcare, agri-products, and manufacturing to create innovative solutions for global problems.

India is carving out its own niche in the global bioeconomy through strong industry-academia collaborations, global partnerships, and green production practices. To drive sustainable and inclusive growth, attention should be directed towards systematic investments in institutional infrastructure, skill development in specialised areas, and overall capacity-building efforts.

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Current State of Play: India in the Global Semiconductor Value Chain*

Semiconductors form the backbone of modern technological advancement, powering industries from artificial intelligence to space tech and exploration. They are foundational to the progress of emerging technologies like photonics and quantum computing. Quantum Computing, in particular, is dependent on scalable quantum processors that rely heavily on advancements in semiconductor materials. As mentioned by Prof. Navakanta Bhat, Dean, Division of Interdisciplinary Sciences, IISc, during the Fireside Chat at the Technology Dialogue 2025, the global semiconductor market is nearing USD 1 trillion, while the market for computing power and electronics is set to surpass USD 10 trillion soon. Consequently, nations around the globe are making strategic moves to secure their place within the semiconductor value chain and its associated supply network. India, with its vast talent potential and ambitious policy initiatives, stands at a critical juncture in the semiconductor landscape.

The Global Semiconductor Race and Interdependence with Emerging Technologies

The COVID-19 pandemic exposed the fragility of global semiconductor supply chains, leading to production delays across multiple industries. With the small island nation of Taiwan producing nearly 90% of the world's most advanced chips and China steadily increasing its market share, major economies like the United States and the European Union responded to these dependencies with inward-looking initiatives like the U.S. CHIPS Act and the European Chips Act, respectively, to bolster their capabilities in semiconductors. These concentrations pose significant risks, particularly for nations that depend on semiconductor imports for their industries and national security. The global semiconductor race is not just about technological supremacy but also about navigating the deep interdependence between semiconductors and emerging technologies, where advancements in AI, quantum computing, renewable energy technology and next-gen communications both drive and rely on semiconductor innovation.

As Dr Andrew White, Centre Director, ARC CoE Quantum Systems, highlighted, while semiconductors play a foundational role in emerging technologies such as AI, 5G, and photonics, they are themselves dependent on advancements in AI and quantum materials. For instance, AI and machine learning applications require high-performance computing, which depends on specialised semiconductor architectures such as Graphics Processing Units (GPUs) and Tensor Processing Units (TPUs). Simultaneously, AI-driven design automation accelerates semiconductor manufacturing and optimisation. Likewise, semiconductors are fundamental in the development and deployment of renewable energy

* *This article draws insights from the Fireside Chat titled 'Positioning India in the global semiconductor value chain,' which was part of the Technology Dialogue 2025.*

Fireside Chat. From left: Prof. Navakanta Bhat (Facilitator), Shri Utpal Shah, Prof. Andrew White

infrastructure. They harness, convert, transfer and store renewable energy as electricity and subsequently move it onto the electric grid with minimal loss of power. Given this symbiotic relationship, countries that establish a robust semiconductor manufacturing ecosystem will not only secure technological sovereignty but also gain a competitive edge in the global economy driven by emerging technologies.

India's Position in the Semiconductor Global Value Chain and Industry's Role

India has long been a key country in semiconductor design, with 20% of the world's semiconductor design talent. Global technology giants such as Intel, AMD, and Qualcomm have established robust design and R&D centres in India, leveraging the skilled workforce. However, the majority of semiconductor patents lie within their home countries. In India, academic institutions like the Indian Institutes of Technology (IITs) and the Council of Scientific and Industrial Research (CSIR) contribute significantly to semiconductor-related patents, yet private participation is very little. The continuously evolving nature of semiconductor technology means companies must act quickly in filing patents to secure their intellectual property (IP). As this sector grows in India, companies must recognise the need for effective IP strategies and prioritise patent filings.

The nature of this industry is such that despite some strengths, growth here is closely bound by the host nation's ability to cultivate an end-to-end ecosystem that comprises chip design, fabrication and packaging solutions. At present, India lags in large-scale chip fabrication and advanced packaging. Recognising this gap, India has launched initiatives to modernise the Semi-Conductor Laboratory (SCL) and dedicated USD 10 billion towards a semiconductor program to set up the India Semiconductor Mission (ISM) aimed at building a resilient supply chain and domestic semiconductor manufacturing ecosystem. The Production Linked Incentive (PLI) scheme and the Design Linked Incentive (DLI) scheme are designed to attract investments in chip fabrication, assembly, and packaging. Additionally, India is fostering partnerships with global semiconductor leaders to bridge gaps in domestic infrastructure and expertise.

In 2024, the government announced new projects catering to testing and packaging facilities as well as fabrication units. Most notably, Mr Utpal Shah of Tata Electronics mentioned during the fireside chat about the USD 14 billion investment towards the establishment of India's first commercial semiconductor fabrication facility in Dholera, Gujarat, along with an indigenous chip Assembly, Testing, Marking and Packaging (ATMP) facility in Jagiroad, Assam. Other Indian private firms are encouraged to follow suit and take similar bold steps in chip design, fabrication and end-to-end packaging to reduce the country's reliance on imports and increase its self-sufficiency in the sector.

Without a targeted effort and clear timelines, India risks falling behind in an arena of technology that thrives on rapid innovation and expertise. It is essential for India to also put efforts into the development of a robust semiconductor workforce. Deeper and more frequent collaborations between academia and industry through specialised semiconductor education and training programs, as well as research collaborations, are pivotal in equipping engineers, workers and researchers with the skill set needed for next-generation chips. Private industry players should also take a proactive role in advancing India's ambitious targets in the semiconductor industry. With the support of government-backed initiatives, private players are poised to generate lots of jobs in this sector in the coming years. As Prime Minister Narendra Modi outlined a larger goal early last year, India aims to expand its electronics sector to USD 500 billion and create 6 million jobs by the end of this decade. Reducing the brain drain through targeted interventions to retain skilled professionals will also be crucial for sustaining long-term growth in this sector.

The Need for Global Collaboration and Charting the Future

India is at the early stages of its commercial semiconductor manufacturing ecosystem, whereas countries like China, South Korea, and Taiwan are already well-integrated into the global semiconductor value chain. While India has taken important steps in its semiconductor journey, certain challenges persist. Gaps in infrastructure, sustainability aspects, huge capital costs to set up semiconductor plants, and the necessity of sustained policy momentum need to be addressed to secure long-term success. Furthermore, integrating semiconductor development within India's broader tech ecosystem, ensuring synergy with innovations in AI and quantum technology, will also determine the success in this sector.

The semiconductor industry is characterised by an intricate supply chain spanning multiple continents. It is common knowledge that the semiconductor manufacturing ecosystem requires high-tech infrastructure for designing, fabrication, research, testing, and packaging, combined with sophisticated tools, minerals, and gases to deliver chips. Given the complexity and capital-intensive nature of the whole semiconductor value chain, global collaboration is essential. India recognises the importance of collaboration and seeks to actively build strategic partnerships with global semiconductor leaders to bridge gaps and drive innovation.

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India's Position in Global AI Diplomacy: Is Global Collaboration the Key to AI Governance?*

Global collaboration on Artificial Intelligence (AI) governance involves coordinated efforts by governments, international organisations, and other stakeholders within national and international AI ecosystems to establish common rules and principles for AI development, deployment, and oversight. AI governance encompasses a broad framework of mechanisms that guide its ethical, technical, regulatory as well as socio-economic impact, ensuring responsible development and deployment.

The recent commercialisation of generative AI technologies, such as OpenAI's ChatGPT in late 2022, has driven business efficiency but also introduced significant challenges that transcend national borders, necessitating stronger global AI governance. However, geopolitical tensions and institutional barriers complicate these efforts. AI governance is uniquely complex due to the unpredictable nature of advanced AI systems and the difficulty in forecasting their societal impact. Power imbalances further hinder regulation, as a few dominant private firms control AI development while many developing nations struggle with limited access to critical AI resources, deepening the digital divide. AI accessibility, inclusion, and sustainability are, therefore, vital components of governance.

While regulations provide the legal guardrails for AI governance, enabling governance mechanisms—such as workforce upskilling, public-private partnerships, adaptive regulatory sandboxes, shared best practices and ethical AI frameworks—help to harmonise AI policies while fostering responsible innovation. Countries that effectively integrate regulatory and enabling governance mechanisms create AI environments that are both innovative and equitable.

Power of Dialogue

Technology diplomacy has emerged as a crucial tool that leverages diplomatic channels to address technology-related issues, such as cybersecurity, internet governance, and digital trade. It involves international relations, dialogue, and negotiations between states, the private sector, civil society, and other groups to shape global digital policies and emerging technological issues. Mechanisms such as AI knowledge-sharing platforms and voluntary best practices play a significant role in fostering consensus[1]. India has been proactive in this arena.

International forums such as Track 1.5 events, bilateral dialogues, and multilateral meetings are instrumental in shaping AI governance. Track 1.5 events, which combine official and non-official

* *This article draws insights from the two-part 'India-France AI Policy Roundtable' series—held in Bengaluru alongside Technology Dialogue 2025 and in Paris as an official side event to the AI Action Summit 2025.*

Experts at the India-France AI Policy Roundtable during Technology Dialogue 2025

participants, facilitate open discussions and exchange of diverse perspectives. These platforms enable stakeholders to address complex issues like AI ethics and equitable access collaboratively.

A recent Track 1.5 roundtable event is the Second India-France AI Policy Roundtable, held on 10 February 2025 in Paris[2]. Organised by the Office of the Principal Scientific Adviser (PSA) to the Government of India, the Indian Institute of Science (IISc), Bengaluru, the IndiaAI Mission (MeitY) and Sciences Po University Paris, it built upon key objectives initiated during the First Roundtable held at IISc, Bengaluru during Technology Dialogue 2025 on 25 January 2025. The roundtables brought together representatives from the government, industry, and other AI experts from both countries to address issues such as foundation models, inclusive AI, digital public infrastructure (DPI) as a model for AI, sustainable AI, global AI governance, and the challenges of balancing sovereign AI with cross-border data flow regulations.

i) India's Leadership in Global AI Landscape

By aligning domestic policies with international collaborations, India seeks to achieve a balanced approach to AI governance. India has actively participated in and, in some cases, led global collaborations to shape AI norms. A notable example is India's role in the Global Partnership on Artificial Intelligence (GPAI), where, as a key member, it has contributed to discussions on responsible AI and following a DPI model to ensure equitable AI adoption. Hosting the GPAI 2023 Summit in New Delhi, India, reinforced the need for AI solutions tailored to diverse socio-economic contexts, especially in the Global South[3].

During its G20 presidency in 2023, the G20 New Delhi Leaders' Declaration advocated a "pro-innovation governance approach" to AI – reflecting India's philosophy of encouraging innovation while curbing risks[4]. India, along with Global South partners, has championed enabling governance models, such as AI capacity-building initiatives and research collaborations, ensuring AI adoption remains inclusive and context-driven. India has also partnered with UNESCO to align national efforts with UNESCO's

Recommendation on AI Ethics while contributing insights to the OECD's AI Policy Observatory, focusing on AI regulatory frameworks tailored to emerging economies[5].

A pivotal moment of international collaboration was the AI Action Summit 2025, hosted by France and co-chaired by India. In his address at the Summit, Prime Minister Narendra Modi highlighted India's success in building digital public infrastructure for its citizens using open and accessible technologies. He stressed the need to "democratise technology" to ensure AI benefits are accessible to all, especially in the Global South[6]. The Summit resulted in a joint declaration titled "Statement on Inclusive and Sustainable Artificial Intelligence for People and the Planet," endorsed by 62 countries and two regional blocs. This declaration emphasised principles such as accessibility, transparency, ethical use, and the promotion of AI as a tool for human development[7].

ii) Regional and Minilateral Partnerships

India has also strengthened AI collaboration through regional partnerships, such as the ASEAN-India Joint Statement on Advancing Digital Transformation, which highlights AI as a key area for cooperation[8]. This aligns with India's broader vision of democratising AI access and ensuring that emerging technologies support equitable growth.

Beyond regional collaborations, India has pursued bilateral and minilateral AI partnerships. The Quad AI Working Group—comprising India, the United States, Japan, and Australia—has facilitated joint research on AI standards and interoperability, with India emphasising the role of open-source AI models to prevent monopolisation by a few major tech giants[9]. Similarly, the India–EU Trade and Technology Council (TTC), launched in 2023, dedicates a track to emerging technologies and AI, where both partners seek common ground on trustworthy and human-centric AI standards[10]. Bilateral collaboration with France has been particularly notable. The Indo-French Roadmap on Cybersecurity and Digital Technology[11] continues to drive innovation, with 2026 designated as the Indo-French Year of Innovation[12].

These different strategic engagements show India's significant role in shaping global AI governance. By advocating for an equitable, open, and innovation-driven AI ecosystem, India is emerging as a critical voice in ensuring AI for good and AI for all, rather than being dictated by a few dominant players. As multilateral AI governance frameworks continue to evolve, India remains at the forefront, striving for an inclusive digital future.

Differing Regional Priorities

The AI Action Summit 2025 also highlighted the divergent approaches to AI regulation – the United States and the United Kingdom declined to sign the declaration, citing concerns over potential overregulation hindering innovation[13].

Despite efforts on convergence, it is to be noted that approaches to AI regulation vary significantly between countries and the Global North and Global South. For instance, nations in the EU often focus on establishing stringent regulatory frameworks to address ethical concerns and potential risks associated with AI deployment. In contrast, countries in the Global South emphasise the need for AI to drive socio-economic development, advocating for frameworks that balance innovation with inclusivity.

Multilateral forums provide platforms for such diverse stakeholders to collaborate on AI governance. However, interstate competition and the evolving landscape of international institutions present challenges to effective global AI governance. As AI becomes a key driver of technological advancement, economies such as China and the U.S. pursue policies to strengthen their leadership in the field. Meanwhile, multilateral organisations navigate complexities related to coordination, overlapping mandates, and differing policy approaches, making cohesive global governance efforts more intricate[14]. Moreover, voluntary initiatives often face obstacles due to vague commitments, non-binding agreements, and slow ratification.

Since leading economies have taken divergent regulatory approaches, multilateral collaboration remains the only viable path to ensuring AI benefits all nations equitably.

Looking Ahead

To harmonise disparate approaches, the establishment of a global AI coordination mechanism under the auspices of international bodies like the United Nations could be instrumental. This approach allows countries to tailor their AI policies to national contexts while adhering to shared future-looking guidelines. In the near-future absence of a universal consensus, regional and bilateral collaborations can serve as effective platforms for developing harmonised AI frameworks.

India's involvement in global efforts has a particularly symbolic significance – it signals that AI is not solely the West's or China's domain. We could witness a domino effect where regional alliances form, and the global governance of AI becomes more geographically representative due in part to India's example of active participation.

Partnerships noted above underscore India's role as a leading voice in shaping AI governance across the Global South. To prevent any forms of digital (or "neo"-) colonialism, governance must incorporate Global South perspectives. As AI has the potential to drive socio-economic progress in these regions, enhancing healthcare, agriculture, and education, organisations like the African Union, BRICS, and G77 play a crucial role in advocating for inclusive AI policies that ensure equitable benefits across diverse global communities.

However, India's impact will also depend on how it navigates future challenges. If geopolitical tensions or domestic constraints limit India's contributions, the world might revert to power-centric governance (dominated by a few). India must overcome domestic hurdles of imported AI systems and gaps in research and development. Other common challenges across the Global South include skewed datasets (often dominated by Global North inputs) and insufficient computing power, leading to biases and unequal outcomes.

India also navigates a complex international landscape of competing governance models. Globally, there is fragmentation in AI governance approaches: the U.S. and allies favour lighter-touch, industry-led guidelines, the EU advocates formal regulation, and China pursues state-driven controls. Forging international consensus is inherently difficult. Even among democratic partners, differences in privacy norms, data governance, and economic priorities create friction. India's own emphasis on digital sovereignty and protecting its markets may not always align with others pushing for more open data flows. Therefore, a balanced AI governance model must integrate safeguards with enabling governance tools—something India actively advocates.

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Valedictory Keynote

India's Techade Vision through Cross-Sectoral Technology Convergence, Foresight and Global Engagements*

Dr Parvinder Maini
Scientific Secretary, Office of the Principal Scientific Adviser to the Government of India

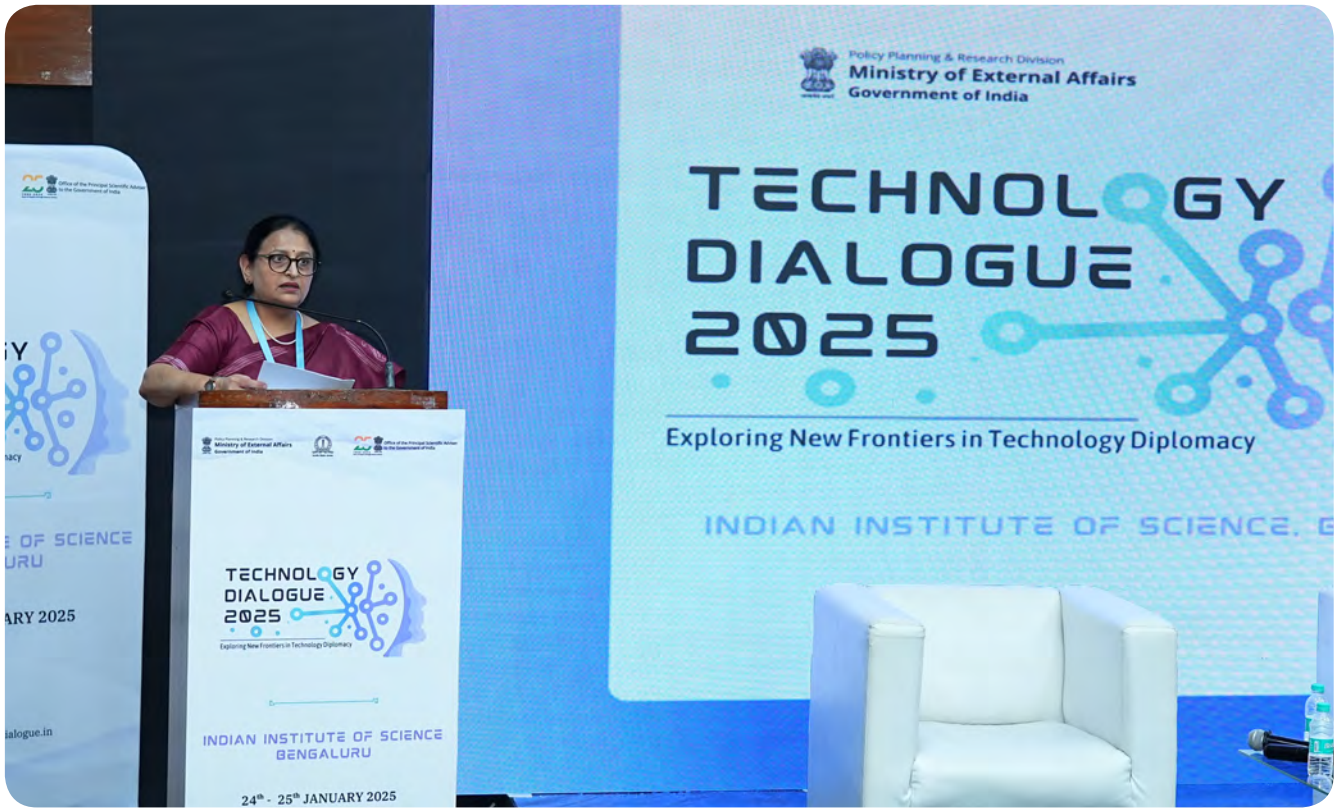
India has committed to making this decade a 'Techade for India', where technological advancements more than ever are expected to drive economic growth, societal progress, and strategic global positioning. The country aims to become a USD 5 trillion economy by 2027 and a USD 7 trillion economy by 2030, driven by research & development, enhanced technology adoption, workforce skilling, and increased global technology trade engagements. Achieving this vision requires a multi-pronged approach to innovation, focusing on deep-tech innovations, technological self-reliance, global competitiveness in high-value manufacturing, and sustainable development.

The government has launched a series of ambitious policies and programmes to strengthen India's technology and industry ecosystem, such as the National Quantum Mission, National Deep Tech Startup Policy (NDTSP), Indian Space Policy, India Semiconductor Mission, IndiaAI Mission, and the latest National BioE3 Policy. These initiatives have pooled in strategic investments in key technological domains. Further initiatives such as the Production-Linked Incentive (PLI) schemes, Digital India, and the Semiconductor Mission aim to position India as a global hub for high-tech manufacturing and R&D while providing robust hardware and software infrastructure for critical sectors such as Aerospace and Defence. For these national initiatives to achieve their full potential, effective cross-sectoral integration is essential. For example, a breakthrough in semiconductor technology can significantly impact the renewable energy sector, given that solar panel systems and smart grids are highly dependent on efficient semiconductors.

Need for Cross-Sectoral Integration & Technology Foresight

As industries undergo rapid transformations globally, siloed approaches to technological development no longer suffice. India must foster synergies between different technology domains, ensuring that advancements in one field catalyse innovation in others. Strategic cross-sectoral collaboration enables better utilisation of technologies and ensures that investments in R&D yield maximal impact.

* *Based on the Valedictory Keynote by Dr Parvinder Maini, Scientific Secretary, Office of the Principal Scientific Adviser to the Government of India.*



Dr Parvinder Maini, Scientific Secretary, Office of the Principal Scientific Adviser to the Government of India

A strong example of this approach is the recent Memorandum of Understanding (MoU) between the Indian Space Research Organisation (ISRO) and the Department of Biotechnology (DBT) for space-based biomanufacturing under the Bharatiya Antariksha Station and BioE3 programmes. This initiative highlights the convergence of space technology and biotechnology, leveraging microgravity environments to enhance bio-manufacturing processes, paving the way for advancements in other fields such as materials science, pharmaceuticals and regenerative medicines. Cross-sectoral integration is equally vital for addressing national challenges such as energy security, healthcare, and climate resilience. For example, combining AI-driven precision agriculture with IoT-enabled smart farming can boost crop yields and resource efficiency while integrating renewable energy developments with advanced battery storage technologies can enhance India's energy security. Fostering cross-sectoral innovation pipelines through industry-academia collaboration, startup incubation programmes, and targeted R&D interventions can accelerate India's transition towards a globally competitive deep-tech ecosystem.

Additionally, there is a need for a dynamic Technology Foresight approach to systematically analyse technological trajectories and align policy planning with long-term sectoral needs and national priorities. It is a structured exercise for identifying emerging, disruptive and critical technologies and anticipating their future impact. The European Union already employs regular technology foresight exercises under its 'Knowledge for Policy' platform, bridging the science-policy gap by bringing together evidence for policy from scientists across Europe to policymakers across Europe. Multidisciplinary centres such as the 'MIT Media Lab' that bring together scientists, engineers, designers, and policymakers to work on futuristic projects across multiple disciplines can be seen as a popular model of cross-sectoral innovation and foresight, too. India needs to establish a cohesive framework for cross-sectoral developments and Technology Foresight that brings diverse stakeholders together. This will ensure that technological advancements and engagements are not just reactive but proactively designed to address future challenges and opportunities. This integrated approach will not only strengthen India's technological capabilities but also enhance its role in global innovation ecosystems.

Global Technology Engagement and the Call for Sustainable Innovation

India's Techade vision is not just about isolated technological advancements but also about fostering an integrated and forward-looking global technology ecosystem. The country is actively engaging in bilateral and multilateral technology engagements through initiatives such as the EU-India Trade and Technology Council (TTC), the UK-India Technology and Security Initiative (TSI), the U.S.-India Initiative on Critical and Emerging Technologies (iCET), and now India-US TRUST (Transforming the Relationship Utilising Strategic Technology). Platforms like the Chief Science Advisers' Roundtable (CSAR), introduced under India's G20 Presidency, reflect India's leadership in shaping global science and technology discourse.

As technology-driven economies evolve, it is imperative that innovations contribute to sustainability, equity, and responsible governance. One of the most pressing challenges of technological expansion is sustainability, some examples being the environmental footprint of semiconductor manufacturing, AI-driven energy consumption, and space debris from satellite mega-constellations. Governments and industries worldwide should plan a shift towards low-carbon computing, water and energy-efficient semiconductor fabrication, and sustainable space activities to mitigate the environmental impact of rapid technological advancements.

As technology reshapes global power dynamics, India should take a proactive approach in fostering inclusive, sustainable, and collaborative technology developments. By strengthening domestic R&D, enhancing cross-sectoral innovation, and deepening global partnerships, India can position itself as a leading player in the global technology landscape. A well-orchestrated approach—combining policy foresight, sectoral convergence, and international collaboration—will ensure that this decade truly becomes the 'Techade for India.'

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This marks the conclusion of the special issue section based on the Technology Dialogue 2025.

Science Beyond Borders: Policies, Opportunities, and Challenges

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Introduction

The insightful panel discussion, *Science Beyond Borders: Policies, Opportunities, and Challenges*, was conducted during the India International Science Festival (IISF) 2024, held from 30 November to 3 December in Guwahati, Assam. IISF, an initiative of the Ministry of Science and Technology and the Ministry of Earth Sciences, Government of India, in association with Vijnana Bharati, aims to engage the public with science in an interactive and enjoyable manner. This session brought together distinguished experts and policymakers to explore the multifaceted dimensions of global scientific partnerships, aligning with the festival's overarching goal of fostering a culture of scientific temper and international cooperation.

In an era of global challenges such as climate change, public health crises, food security, and energy needs, science and technology have emerged as powerful instruments for fostering international cooperation. Science diplomacy—the use of scientific collaborations among nations to address global issues—has gained prominence as a driver of both scientific progress and international relations. The panel discussion aimed to address the critical role of cross-border scientific collaborations in addressing these pressing concerns.

Chaired by Prof. Ashutosh Sharma, President of the Indian National Science Academy (INSA) and former Secretary, Department of Science and Technology (DST), the panel featured leading experts: Dr Nitin Seth, Director, Indo-French Centre for the Promotion of Advanced Research (CEFIPRA); Shri R. Madhan, Director, Indo-German Science and Technology Centre (IGSTC); Dr Praveen Kumar S, Head, International Cooperation, DST; Dr. Rama Swami Bansal, Head, International S&T Affairs Division, Council of Scientific and Industrial Research (CSIR); and Dr Yelloji-Rao Mirajkar, International Convener, Global Indian Scientists and Technocrats (GIST) Forum.

The session explored multidimensional aspects of international scientific cooperation, including policy frameworks, intellectual property (IP) concerns, mobility gaps, and the need for equitable partnerships. This report synthesises the discussions while providing broader insights into science diplomacy and its implications for India.

Rationale for International Scientific Collaboration

Science thrives on the free flow of ideas, expertise, and resources. Historically, international collaborations have been driven by groundbreaking discoveries. Examples such as the European Organization for

Nuclear Research (CERN), the International Space Station (ISS), the Human Genome Project (HGP), and the Intergovernmental Panel on Climate Change (IPCC) illustrate the transformative potential of cross-border partnerships. Together, these initiatives reflect the spirit of *Science Beyond Borders*, underscoring the immense value of global cooperation in advancing scientific knowledge, addressing global challenges, and promoting a sustainable and equitable future for all.

From an Indian perspective, international collaborations have been instrumental in advancing research capabilities and addressing national priorities. Institutions like IGSTC and CEFIPRA serve as successful models of bilateral scientific cooperation. Shri R. Madhan, Director, IGSTC, highlighted that modern scientific collaborations extend beyond conventional knowledge exchange, including infrastructure sharing, workforce development, and diverse problem-solving in critical areas. By enabling Indian researchers to access specialised laboratories, advanced instruments, and valuable datasets, infrastructure sharing empowers them to work on pioneering technologies at the global forefront. Similarly, initiatives like exchange programs, fellowships, and joint research endeavours are pivotal in capacity building, equipping scientists with the skills and experience necessary to address emerging challenges. Moreover, the inclusion of diverse perspectives through international partnerships fosters innovative approaches to tackling complex global issues, reinforcing the transformative potential of cross-border collaborations in science and technology. Such partnerships are essential for addressing global problems like pandemics, renewable energy, and water resource management.

Science Diplomacy: A Strategic Tool for Geopolitical and Scientific Advancement

India has positioned itself as a key player in science diplomacy through initiatives such as the India-Africa S&T Cooperation, the BRICS Framework for Science and Technology, India's Space Debris Mitigation with Japan, Australia-India Green Hydrogen Cooperation and India-France AI Partnership, to name a few. Dr Seth highlighted that Indo-French collaborations, particularly in renewable energy, health sciences, and artificial intelligence (AI), exemplify win-win partnerships that drive innovation and capacity building.

Prof. Ashutosh Sharma, President of INSA, aptly noted that science is both cooperative and competitive. While international partnerships foster collaboration, nations remain protective of their IP and technological advancements. Balancing cooperation with national interests is central to effective science diplomacy.

Role of Policies in Enabling Cross-Border Science

Policies serve as vital enablers for international collaborations by establishing clear frameworks that address key aspects of joint research and innovation. They provide guidelines for IP sharing, ensuring clarity on the ownership and commercialisation of outcomes from collaborative efforts, which is crucial for fostering trust among partners. Additionally, policies on data governance create rules for secure and ethical data sharing, particularly in sensitive and rapidly evolving fields such as AI and genomics. These policies further reduce barriers by simplifying regulatory processes related to international travel, research funding, and technology transfer, enabling seamless collaboration and the effective exchange of knowledge, resources, and technologies across borders.

Dr Rama Swami Bansal, Head of ISTAD at CSIR, stressed the importance of reciprocal frameworks in collaborations, aligning with India's draft Science, Technology, and Innovation (STI) Policy 2020, which advocates leveraging global partnerships to achieve technological self-reliance while contributing to global innovation ecosystems.

However, challenges remain. As Dr Praveen Kumar S, Head of International Cooperation at DST, highlighted, while data policies are critical for future collaborations, they also create complexities. The exponential growth of data in fields such as AI, quantum computing, and climate modelling calls for robust international data security and privacy regulations.

Mobility Challenges: Addressing the Imbalance

Cross-border mobility of researchers is fundamental to scientific collaborations. However, panellists noted that while Indian researchers frequently travel abroad, reciprocal exchanges remain limited. Dr Nitin Seth, Director, CEFIPRA, discussed efforts to enhance mobility under Indo-French programmes, focusing on short-term mobility schemes for students to gain international exposure. He also emphasised the balanced hosting of workshops and seminars in both India and France, fostering collaborative learning and mutual understanding.

Despite India's state-of-the-art infrastructure—particularly in institutes under CSIR and the Indian Institutes of Technology (IITs)—barriers such as academic calendar mismatches, cultural differences, and perceptions about working conditions discourage researchers from other countries. This mobility gap is not unique to India. Researchers from developing nations face challenges in securing travel funding

and institutional support for international exchanges.

To enhance mobility, the panel suggested:

- Developing Short-Term Research Programs: Offering 15-30 day research exchanges aligned with global academic calendars.
- Promoting Thematic Partnerships: Creating focus areas such as AI, climate technology, and health sciences to attract foreign researchers.
- Strengthening Research Ecosystems: Enhancing infrastructure, support systems, and cultural acclimatisation for visiting scholars to ensure a conducive research environment.

Balancing Intellectual Property and Global Cooperation

IP sharing remains a contentious issue in international collaborations. As Shri Madhan pointed out, conflicts often arise when IP ownership is undefined at the start of a project. The panel advocated for project-specific agreements that clarify IP rights while ensuring equitable benefit-sharing. Additionally, there is a growing need for a global IP framework akin to multilateral arrangements under the BRICS framework. Such a system would provide standardised regulations, enabling scientists to focus on research without legal ambiguities.

Dr Yelloji-Rao Mirajkar, GIST Forum, introduced a unique perspective, advocating for public-domain outputs in collaborations involving NGOs and global forums. For certain sectors, prioritising open science over proprietary interests can accelerate progress on pressing global challenges.

Conclusion

India's leadership in global science diplomacy is increasingly evident through initiatives such as the G20 Presidency's focus on scientific collaborations, strengthened partnerships with the Global South, and the Indo-Pacific Science and Technology Cooperation. As Prof. Ashutosh Sharma summarised, India must adopt a balanced approach—prioritising national interests while contributing to global innovation ecosystems, reinforcing the ethos of "Vasudhaiva Kutumbakam"—the world is one family.

The *Science Beyond Borders* discussion underscored the significance of international scientific collaborations in fostering innovation and addressing global challenges. By addressing challenges like policy gaps, mobility imbalances, and IP conflicts, nations can unlock the full potential of cross-border partnerships. For India, science diplomacy presents a strategic opportunity for leadership in global scientific initiatives. Through well-structured policies, reciprocal collaborations, and investments in the research ecosystem, India can solidify its position as a hub for international scientific cooperation. As science continues to transcend borders, fostering equitable, transparent, and impactful partnerships will remain crucial to shaping a sustainable and prosperous future. The future of science lies not in isolation but in collaboration—where nations unite to solve the greatest challenges of our time.

MoUs Signed

CSIR-NAST MoU: Strengthening India-Nepal S&T Collaboration

India and Nepal have taken a significant step towards enhancing their Science and Technology (S&T) cooperation with the signing of a Memorandum of Understanding (MoU) between the Council of Scientific and Industrial Research (CSIR), India, and the Nepal Academy of Science and Technology (NAST). The agreement was formalised on 18 February 2025 at CSIR-National Physical Laboratory (CSIR-NPL), New Delhi, by Dr. N. Kalaiselvi, Director General, CSIR, and Prof. Dr. Dilip Subba, Vice-Chancellor, NAST. The MoU revitalises longstanding collaboration. It facilitates joint research, scientist exchanges, and capacity-building initiatives in key areas, including biotechnology, environmental science, materials research, alternative energy, and drug discovery. Both institutions reaffirmed their commitment to leveraging scientific advancements for mutual growth, marking a new era in the Indo-Nepal S&T partnership.

India and Argentina sign MoU in Lithium Exploration and Mining

India and Argentina have taken a significant step towards strengthening cooperation in the mining sector with the signing of a MoU between Mineral Exploration and Consultancy Limited (MECL) and the Provincial Government of Catamarca. The agreement, formalised during a high-level meeting in New Delhi on 19 February 2025, aims to enhance collaboration in lithium exploration and the development of critical mineral resources. As part of the global 'Lithium Triangle,' Argentina is a key partner in securing essential minerals for India's clean energy transition. Discussions focused on expanding Indian participation in Argentina's mining projects, exploring investment opportunities, and establishing long-term supply agreements. The MoU reinforces India's commitment to diversifying its mineral supply chains and fostering international partnerships in resource security. By facilitating deeper engagement in lithium exploration and investment, this collaboration is expected to accelerate India's energy transition, support electric vehicle manufacturing, and contribute to global sustainability goals.

New Publications

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Call for Proposals

Australia-India Strategic Research Fund 2025
Last Date: April 11, 2025
Further information at: https://onlinedst.gov.in/Projectproposalformat.aspx?Id=2115

Indo-French Call for Joint Research and Innovation Project Proposals
Last Date: May 06, 2025
Further information at: https://onlinedst.gov.in/Projectproposalformat.aspx?Id=2358

India-Spain Joint Call for R&D&I Projects
Last Date: May 20, 2025
Further information at: https://tdb.gov.in/india-spain-joint-call-rdi-projects-2024

DST DFG Joint Call on International Research Training Groups
Last Date: August 01, 2025
Further information at: https://onlinedst.gov.in/Projectproposalformat.aspx?Id=2232

Forthcoming Events

Johns Hopkins Science Diplomacy Summit 2025
Date: April 14-15, 2025

Further information at:
https://hub.jhu.edu/events/2025/04/14/johns-hopkins-science-diplomacy-summit-2025/

2025 Science for Policy Conference

Date: May 26-27, 2025
Further information at:
https://scientificadvice.eu/conference/

GYA Annual General Meeting and International Conference

Date: June 10-13, 2025
Further information at:
https://agm.globalyoungacademy.net/