Cross-Sector Collaborations and Research Alliances Within Indian Universities and Private Sector: A Perspective on the Sustainable Nanotechnology Sector
**Introduction**

Sustainable development has always been and will be a necessity, and it is no longer pragmatic to pretend ignorance towards it. The United Nations declaration of Sustainable Development Goals (SDGs) is an assertion of the above fact after 24-year long contemplation (UN DESA, 2015). Sustainable technologies or technologies that contribute to one or more aspects of sustainable development can serve as a key pillar to achieving most of the SDGs. Therefore, identifying emerging sustainable technologies and their potential is vital so that the country reaps maximum benefit through effective policy interventions. Nanotechnology encompasses several general-purpose technologies that coexist at the intersection of different technological paradigms (Prabhakaran et al., 2019). The emerging sustainable nanotechnologies (ESNTs) or simply SNTs have the potential to address global challenges, such as water purification, clean energy technologies, green-house gases management, materials supply and utilisation, and green manufacturing and chemistry (Beumer & Bhattacharya, 2013). One such technology is, nanotechnology-based membranes is being used by commercial water purifier manufacturers for recycling and reusability of wastewater (Hoek et al., 2014).

One of the major characteristics of flourishing innovation systems to ensure societal benefits from ESNTs is the existence of strong University-Industry (U-I) linkages backed by robust policy frameworks. In the Indian context, the gap between policies and the ground reality of University-Industry Linkages (UIL) and the need for addressing obstacles such as institutional bottlenecks were acknowledged by the Department of Scientific and Industrial Research (DSIR, 2019). Major funding efforts in nanotechnology in India can be credited to the Department of Science & Technology (DST),...
Defence Research and Development Organization (DRDO), Department of Information Technology, Department of Atomic Energy (DAE), Department of Biotechnology (DBT), Council for Scientific and Industrial Research (CSIR), Indian Council of Medical Research (ICMR) and Ministry of New and Renewable Energy (MNRE) (Beumer & Bhattacharya, 2013). Over the period 2001-2011, DST-Nano Mission, Department of Electronics and Information Technology (DeitY)-Nanoelectronics and DBT had invested Rs. 1000 Crore (USD 200 M), Rs. 500 Crore (USD 100 M) and Rs. 100 Crore (USD 20 M) respectively for nanotechnology (Ramaraju, 2012). Over the years, India’s productivity (Fig. 1) in nanotechnology has increased, evident from the transition in the number of granted patents in nanotechnology to India by the United States Patent and Trademark Office (USPTO). However, the growth rate in patented innovations remains lower than the other advanced economies, mainly the United States of America, South Korea, China, Japan, and the United Kingdom (based on the USPTO granted patent data refined by the nanotechnology-related IPC codes such as B82) as shown in Fig. 1. Over the years, India’s productivity (Fig. 1) in nanotechnology has increased, evident from the transition in the number of granted patents in nanotechnology to India by the United States Patent and Trademark Office (USPTO). However, the growth rate in patented innovations remains lower than the other advanced economies, mainly the United States of America, South Korea, China, Japan, and the United Kingdom (based on the USPTO granted patent data refined by the nanotechnology-related IPC codes such as B82) as shown in Fig. 1. In this article, we analyse various facets related to the policy interests of India with respect to ESNTs, especially the ones for strengthening UIL.

Policy Interests in India's Sustainable Nanotech Sectors and Engagements

Economies worldwide are trying to transition into a 'sustainable economy' to meet the world's environmental, economic, and social challenges. Nanotechnology as a multidisciplinary field has the potential to offer solutions to these global sustainability problems. It involves innovations across almost every technology field, including materials science, biology, physics, chemistry, engineering, and computer science. Further, in the current techno-economic paradigm, harnessing general-purpose technologies (Jovanovic & Rousseau, 2005; Perez, 2009) like nanotechnology play a vital role in a country's economic and social development. The immense potential of nanotechnology and various technology applications have encouraged Indian policymakers to nurture nanotechnology research and development (R&D). India hopes to become a global nanotechnology hub to have a first-mover or first-follower advantage over its counterparts. Unfortunately, only a few of its technologies have been successfully commercialised for the mass market, despite several efforts from central and state governments through programs such as the ‘Nano Mission’ and nanotechnology centres of excellence. This indicates that UIL is still nascent in nanotechnology research for the Indian R&D ecosystem (Beumer & Bhattacharya, 2013).

In 2001, the Nano Science and Technology Initiative of the Government of India (GoI) incentivised the formation of a nanotechnology innovation ecosystem immediately after the USA launched their National Nanotechnology initiative. This DST-led initiative emphasised having an interface between academia and industry other than the core activities of supporting research in priority areas like nanomaterials, nanomedicine, and nanoelectronics. The sector received continued outlays by 11th and the following Planning Commissions after the launch of Nano Mission in 2007 (GOI Cabinet, n.d.). India adopted a different way of governing emerging technologies through mission-mode-driven action plans. Mission-mode implies that “projects have clearly defined objectives, scopes, and implementation timelines and milestones, as well as measurable outcomes and service levels” (Meity, 2020). This mission-mode
model facilitated the development of the Indian economy and technology governance (Beumer, 2018). As part of the mission-mode model, a multi-pronged policy approach was adopted to influence the nanotechnology ecosystem through technology development by considering the needs of modern society, achieving self-dependency, international cooperation, and others. A series of nanotechnology centres of excellence were established around the country to develop a strong institutional base and skilled workforce for nanotechnology R&D. Several state governments were also roped in through state-level initiatives to support nanotechnology development. A National Centre for Nanomaterials was established at the International Advanced Research Centre for Powder Metallurgy and New Materials (ARCI) in collaboration with Germany, Japan, Russia, Ukraine, and the US. India also entered into bilateral nanotechnology programmes with the US, European Union, Italy, Taiwan, and Germany (Bhattacharya et al., 2012). Despite all of these, investments remained well below the global average, with stagnant research calibre at the global level incentivised the formation of a nanotechnology innovation ecosystem immediately after the USA launched their National Nanotechnology initiative. This DST-led initiative emphasised having an interface between academia and industry other than the core activities of supporting research in priority areas like nanomaterials, nanomedicine, and nanoelectronics. The sector received continued outlays by 11th and the following Planning Commissions after the launch of Nano Mission in 2007 (GOI Cabinet, n.d.). India adopted a different way of governing emerging technologies through mission-mode-driven action plans. Mission-mode implies that “projects have clearly defined objectives, scopes, and implementation timelines and milestones, as well as measurable outcomes and service levels” (Meity, 2020). This mission-mode model facilitated the development of the Indian economy and technology governance (Beumer, 2018). As part of the mission-mode model, a multi-pronged policy approach was adopted to influence the nanotechnology ecosystem through technology development by considering the needs of modern society, achieving self-dependency, international cooperation, and others. A series of nanotechnology centres of excellence were established around the country to develop a strong institutional base and skilled workforce for nanotechnology R&D. Several state governments were also roped in through state-level initiatives to support nanotechnology development. A National Centre for Nanomaterials was established at the International Advanced Research Centre for Powder Metallurgy and New Materials (ARCI) in collaboration with Germany, Japan, Russia, Ukraine, and the US. India also entered into bilateral nanotechnology programmes with the US, European Union, Italy, Taiwan, and Germany (Bhattacharya et al., 2012). Despite all of these, investments remained well below the global average, with stagnant research calibre at the global level and inadequate human resources (Ghosh & Krishnan, 2014).

**Barriers to the Diversification of Cross-Sectoral Collaborations Across U-I Linkages**

The barriers to increasing U-I engagement for successful nanotechnology commercialisation can be broken down into sector-specific challenges, incentives of the actors, and the lack of a systemic framework, which we henceforth term a ‘triad of barriers.’ Attempts have been made by the Indian legislature to introduce a governing framework through the Protection and Utilisation of Public-Funded Intellectual Property Bill. However, the bill was modelled directly after the United States Bayh-Dole act
and failed to account for the Indian context and needs. The Bill’s focus was primarily on patent rights issues, which in the Indian context is not the primary impediment to their licensing and subsequent productive utilisation (CIS, 2011). Due to the lack of an overall framework for negotiating the tensions between the various responsibilities of government-funded research institutes, commercialisation incentives for researchers are limited and highly institute-specific. Most academics, perhaps wisely, choose to focus on well-validated metrics of success, such as publications and teaching, rather than risk commercial engagement where failure rates can be higher and the time investment is significant (UGC, 2019). With the limited R&D tax incentives and joint funding initiatives currently available, the industry has had a sparse engagement with academia (DSIR, 2019). There is limited scope for the exchange of personnel between universities and industry, except at select well-funded institutes resulting in a lack of critical mass of trained personnel. Even when a potential opportunity emerges, the commercial risks to bringing a product to market in the nanotechnology sector are enormous and require capital for scaling from a lab-bench prototype (Purushotham, 2012). The capital is often missing in Indian industry, largely composed of micro, small and medium enterprises (MSMEs) that have little internal R&D activity of their own. Nanotechnology R&D is highly capital intensive, requiring millions of dollars of instrumentation for analysis and development. Such capital investments are not possible at an individual MSME and require collaborative facilities. However, these facilities are primarily situated in academic campuses with high bureaucratic barriers to access. The recent focus on entrepreneurship by the government is an important step toward addressing the inability of established businesses to engage intensively in R&D and ensuring the commercial “valley-of-death” is bridged (Purushotham, 2012; Aithal & Aithal, 2016). However, the start-ups need easy access to advanced instrumentation and more streamlined access to markets.

**Boosting Cross-Sectoral U-I Cooperation in the Indian Nanotech Industry**

U-I linkages are the enabler for promoting industrial and innovation ecosystems. The diagnosed triad of barriers impeding U-I linkages demands greater attention from policymakers, regulators, and researchers. In order to nurture U-I cooperation, the government needs to proactively establish institutional mechanisms and policy interventions to develop regulatory structures, institutional collaboration incentives and guidelines, and commensurate funding opportunities appropriate for the demands of the sector. These approaches can be amalgamated after careful considerations of the maturity of the nanotech ecosystem in respective Indian states, city-based innovation clusters, and industrial corridors. India needs to develop a definitive action plan by identifying clear targets and deliverables for strategic and sustainable priorities with domestic and future relevance.

The policy strategies discussed herein address the barriers from the triad individually. There is a need to harmonise nanotechnology specifications; for example, the definition of nanoforms varies with regulator and country globally depending upon size, solubility, aggregates and agglomerates, natural or engineered type, distribution thresholds, and properties of nanoparticles. Technical committees can be constituted to address similar issues to harmonise definitions, specifications, regulations, safety, evaluation, ethics, and standardisation of nanomaterials or compositions. Submissions of these
committees can provide clarity to the practitioners and can smoothen interaction across stakeholders. For example, the Canadian Food Inspection Agency and Public Health Agency of Canada regulate nanoproducts through the Food and Drugs Act; or Regulation (EU) No. 2015/2283 and Regulation (EU) No. 1169/2011 provide guidance on risk assessment of nanomaterials in the food and feed additives or pesticides. Some countries like Taiwan brought Nano-Mark certification systems, and Thailand brought NanoQ labels for nanoproducts. Even India is gearing up and recently released guidelines for evaluating nanopharmaceuticals in 2019 (DBT, 2019) and agricultural input and food products in 2020 with the DBT, GoI (DBT, 2020).

The valley of death observable in the nanotechnology life cycle results from a lag in translating inventions into commercial products. We highlight the lack of incentives and motivation among academic innovators to push inventions towards the top-end of the readiness levels. Industrial counterpart faces a similar lack of incentives and thrust in absorbing inventions from academia.

The valley of death observable in the nanotechnology life cycle results from a lag in translating inventions into commercial products. We highlight the lack of incentives and motivation among academic innovators to push inventions towards the top-end of the readiness levels. Industrial counterpart faces a similar lack of incentives and thrust in absorbing inventions from academia. A study by Saha (2015) in the Indian context showed that the likelihood of the market success of the university inventions is perceived lower by the industrial counterparts by alleging the lack of significant technological value additions in those inventions. Provisions of royalty fees, innovators' share of royalty, and consultancy revenue can incentivise scientists and staff of a university or motivate them for technology commercialisation (Saha, 2015). Funding bodies can also adopt frameworks that can bridge the valley of death, such as the mission-mode fast-track translation projects between industry and universities, strengthening the entrepreneurial culture. Many best practices already exist in other countries to draw from in this arena, e.g., collaborations at Japanese universities and industries (Motoyama, 2014), Indo-US Science and Technology Forum (IUSSTF, 2000), and Catapult Centres of the UK (Catapult Network, 2020). Policymakers can enforce a series of carefully designed program level activities for implementing policies, including multi-stakeholder consultations across the industry, university, faculty, and students; establishing a ministry-affiliated office or statutory body for realising ease of doing research and reducing administrative red tapes and bureaucracy; creating U-I facilitation fund for fast-track translation projects, technology or business incubation, intellectual property rights, and entrepreneurial activities at U-I level; personnel exchange or mobility program to-and-fro university and industry; and enhanced recognition or incentivisation to translation projects (UGC, 2019).

The Challenges Ahead: Strengthening the Triple Helix Nexus

So far, very few nanotechnology sector products have been commercialised by Indian universities, and this can be observed in the low level of investments and patenting activities (Ghosh & Krishnan, 2014). To some extent, organised efforts from universities for the establishment and strengthening of U-I linkages can be a solution for this. On the other hand, initiatives for collaboration and establishment of U-I linkages can come from the side of industries too. Adoption of the ‘capability to connectivity model’ along the lines of the ‘Open innovation’ paradigm is
visible (Lathabai et al., 2015) in many industries, and nanotechnology firms are following suit. While efforts to expand and utilise connectivity for the process for innovation should come from industries, academia should be ‘capability-ready’ to participate effectively in the process. The government’s major role in the triple helix model of industry-academia-government interactions for fostering economic and social development (Etzkowitz & Leydesdorff, 1995) should assist universities in improving their capability that centres of excellence can be nurtured and establish interfaces for U-I collaboration. Interfaces should be capable of reaching out to industry and universities for collating their requirements, determining possibilities of complementary action and acting as an enabler of technology transfer and commercialisation. In the case of ESNTs, since there are very few dedicated industrial firms in India, universities should take more responsibility in promoting technopreneurship through encouraging start-ups through incubation centres, intellectual property rights (IPR) cells, creation and management of investor base and expert base, etc., along with the capacity building. Finally, major policy recommendations that can be considered at the level of Government for the establishment of a strong ‘Nano ecosystem’ backed by triple-helix are listed below.

Policy recommendations

- Accelerate technopreneurship activities and attract investment in Nanotechnology. Suggested program-level activities are:
  - Identify potential hotspots of nanotechnology clusters and form SEZs wherever applicable.
  - Allocate handhold-funding for potential but struggling startups via special programs in addition to startup schemes.
  - Encourage the establishment of industrial clusters of nanotechnology firms in leading cities that are well connected to academic and industrial hubs. These firms can work in synergy with biotech and IT firms if required.
  - Engineer the establishment of nanotech parks even in remotest parts of the country, just like the biotech park being established in some villages of the north-eastern states.
  - Strengthen academia-industry ties to ensure the journey of nanotechnological innovations from 'lab to society'.

Suggested program-level activities are:

- Establish interfaces for the formation and management of UILs
- Ensure intervention of the interfaces at right junctures to minimize administrative hurdles and bureaucratic deferments
- Ensure service of interfaces in procuring support of local govt. bodies starting from block/panchayat levels in popularisation and supply of game-changing nanotech products
- Incentivise nanotechnology-based projects that address SDGs in the form of monetary rewards, tax reductions, awards and recognitions, reduced import/export license fees
- Facilitate the supply of trained professionals in the nanotech sector for industrial needs from academia by ensuring industrial and governmental incentives to academia
Facilitate the IP management for potential and viable innovations in the nanotech sector that originates through UILs.

Establish conducive conditions for ‘Nano ecosystem’ to flourish in the country. Suggested program-level activities are:

- Revive the once-rejected PUPFIP bill, which is inspired by the United States’ Bayh-Dole Act (that played a major role in establishing triple-helix there), with the incorporation of suitable modifications addressing the specific concerns at Indian Context as suggested by DSIR (2019) to make legislation and set up or designate bodies for its implementation.

- Formulate a three-pillar framework- a legal framework compliant with the above bill, an ethical framework guided by ‘Nano Ethics’, and a framework for ‘Environmental impact assessment of nanotechnology’ that could synergistically ensure SDG compliance.

References


