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Nanotechnology Development in India: An Overview

Amit Kumar*

Abstract: Nanotechnology has been heralded as a revolutionary technology by many scholars worldwide. Being an enabling technology, it has the potential to open up new vistas in the field of R&D in various multiple disciplines and have wide domain of sectoral applications, ranging from healthcare/medicines, electronics, textiles, agriculture, construction, water treatment, and food processing to cosmetics. Much of these applications are very much pertinent for a developing country like India. In this context, the government has been playing a pioneering role in fostering and promoting nanotechnology R&D in India since early 2000s. This discussion paper attempts to capture the nanotechnology development in India by highlighting the various initiatives undertaken by the government to promote basic R&D in it, the major actors involved and the state of regulatory framework existing in the country. It also looks into these aspects vis-à-vis certain global initiatives/trends.

Keywords: Nanotechnology, nanomission, risk and regulation, capacity building, environmental and health impacts

1. Introduction: Nanotechnology and Its Implications

Nanotechnology is a multidisciplinary as well as an interdisciplinary area of inquiry and application. The broad spectrum of applications that nanotechnology is and will be catering to speaks of its omnipresence. Be it in agriculture, energy, electronics, medicine, healthcare, textiles, transport, construction, cosmetics, water treatment etc., nanotechnology finds a role to play or rather a 'defining role' to play, as suggested by many scholars worldwide.

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The ideas and concepts behind nanoscience and nanotechnology started with a talk entitled “There’s Plenty of Room at the Bottom” by physicist Richard Feynman at an American Physical Society meeting at the California Institute of Technology on 29 December 1959 (Fenyman 1960), long before the term nanotechnology was used. In his talk, Feynman described a process in which scientists would be able to manipulate and control individual atoms and molecules. Over a decade later, in his explorations of ultra precision machining, Prof. Norio Taniguchi coined the term nanotechnology (Taniguchi 1974). It wasn’t until 1981, with the development of the scanning tunneling microscope that could aid in viewing individual atoms that modern nanotechnology began. Eric Drexler expanded Taniguchi’s definition and popularised nanotechnology in his book *Engines of Creation: The Coming Era of Nanotechnology* (Drexler 1986).

Nanoscience is the study of phenomena and manipulation of materials at atomic, molecular and macromolecular scales, in order to understand and exploit properties that differ significantly from those on a larger scale. Nanotechnologies are the design, characterisation, production and application of structures, devices and systems by controlling shape and size on a nanometer scale. At this scale, the general physical, chemical, electrical, biological and optical properties of a material start behaving in a unique and peculiar way. This uniqueness and peculiarity opens up new vistas for enquiry and applications.

In technical terms, nanotechnology has been defined by many scholars and organisations worldwide (see Table 1).

Nanotechnology, being an enabling technology of emerging techno-economic paradigm, is still in the nascent phase of its research, development and innovation. Considering the new and distinct features of nanotechnology, many researchers, scientists and academicians propose that it is a new emerging disruptive technology, which is quite different from sustaining technologies.[1] A technology is considered disruptive when its utilisation generates products with

Table 1: Definitions of Nanotechnology

Source	Definition
US: National Nanotechnology Initiative (2001-)	Nanotechnology is the understanding and control of matter at dimensions of roughly 1 to 100 nanometers, where unique phenomena enable novel applications. Encompassing nanoscale science, engineering and technology involves imaging, measuring, modelling, and manipulating matter at this length scale.
EU: 7th Framework Programme (2007-2013)	Generating new knowledge on interface and size-dependent phenomena; nanoscale control of material properties for applications; integration of technologies at the nanoscale; self-assembling properties; nano-motors; machines and systems; methods and tools for characterisation and manipulation at nano dimensions; nano precision technologies in chemistry for the manufacture of basic materials and components; impact on human safety, health and the environment; metrology, monitoring and sensing, nomenclature and standards; exploration of new concepts and approaches for sectoral applications, including the integration and convergence of emerging technologies.
Japan: Second Science and Technology Basic Plan (2001-2005)	Nanotechnology is an interdisciplinary S&T that encompasses IT technology, the environmental sciences, life sciences, material sciences, etc. It is for controlling and handling atoms and molecules in the order of nano (1/1 000 000 000) meter, enabling discovery of new fuctions by taking advantage of its material characteristics unique to nano size, so that it can bring technological innovation in various fields.

Table 1 continued...

Table 1 continued...

Working definition of ISO TCC 229 in 2007	Understanding and control of matter and processed at the nanoscale, typically, but not exclusively, below 100 nanometers in one or more dimensions where the onset of size-dependent phenomena usually enables novel applications. Utilising the properties of individual atoms, molecules and bulk matter, to create improved materials, devices, and systems that exploit these new properties.
European Patent Office	The term nanotechnology covers entities with a geometrical size of at least one functional component below 100 nanometers in one or more dimensions susceptible of making physical, chemical or biological effects available which are intrinsic to that size. It covers equipment and methods for controlled analysis, manipulation, processing, fabrication or measurement with a precision below 100 nanometers.

Source: OECD (2009).

different performance attributes that may not have been valued by existing customers (Bower and Christensen 1995). Moore (1991) adds clarity to this aspect of disruptive technologies by noting the generation of discontinuous innovations that require users/adopters to significantly change their behaviour to use the innovation. Tushman and Rosenkopf (1992), Anderson and Tushman (1990), and Kassicieh *et al*. (2002) state that disruptive technologies are scientific discoveries that change the usual product/technology paradigms and provide a basis for a new more competitive one. Walsh and Linton (2000) argue that disruptive technologies can either be a new combination of existing technologies or new technologies whose applications to problem areas or new commercialisation challenges can cause major technology product paradigm shifts or create entirely new ones. The point to draw from here is that in case of nanotechnology, both innovation and innovation framework takes a change-over.

In the first years of the new millennium, governments around the world created national nanotechnology programmes that spent billions of dollars (Roco 2003), reconfigured institutional arrangements, and constructed new sites for research and development. Many of these actors present nanotechnology as an enabling platform for other transformative innovations that will become even more powerful through its convergence with biotechnology, information technology, and cognitive science.

A number of observers have catalogued societal issues that emerging nanotechnologies may raise. The early treatment by Roco and Bainbridge (2001), for example, includes implications of economic, political, educational, medical, environmental, and national security import, as well as potential consequences for privacy and global equity (the "nanodivide"). Moore (2002) divides the implications of nanotechnology into three categories: social, including environmental, health, economic, and educational; ethical, including academic-industry relations, abuse of technology, social divides, and concepts of life; and legal, including concepts of property, intellectual property, privacy, and regulation.

2. Global Trends

Worldwide governments have launced many nanotechnology-specific initiatives/programmes to leverage the potentialities of nanotechnology for social and economic gains. In 2005 itself, more than 62 countries launched national nanotechnology-specific activities world over (Maclurcan 2005).

The research and development (R&D) effort was significantly promoted world over with the announcement of the National Nanotechnology Initiative (NNI) in the 2001 by the USA. Most advanced countries have based their own programmes on the groundwork laid by the NNI. The NNI is the most comprehensive R&D programme in nanoscience and technology in the world. The focus of NNI is on research and development of nanoscale science and technology for economic benefit and national security. Its programmes are aligned with the goals of the participating agencies. It has got a flexible R&D infrastructure which consists of centers, networks and user facilities as well as companies with nanotechnology products. In case of Europe, most countries have government-supported major nanotechnology research and development (R&D) initiatives. China has invested in nanotechnology through its medium and long term programmes. The National Enabling Technologies Strategy (NETS) was launched by the Australian Government to provide a structure for the responsible development of enabling technologies such as nanotechnology and other new technologies as they emerge in Australia. In 2003, Taiwan launched its National Science and Technology Programme for Nanoscience and Nanotechnology. Taiwan has also developed Nano Mark which is the world's first government-established system for certifying nano-products. The government spending on nanotechnology in Republic of Korea has increased by a considerable amount as compared to previous years. Its NNI mainly focuses on improving Korea's position in the world in certain competitive areas. Nanotechnology in Japan is largely financed by government agencies and large corporations. It is a leading country in areas like nanomaterials, nanoelectronics, and nano-bio-devices. In Singapore, the nanotechnology funding is done through Agency for Science, Technology and Research that was started in September 2001 with a goal of beginning nanotechnology research as part of Singapore's effort to build on accumulated capabilities and the promotion of innovations in areas that fuel Singapore industries. Canada's nanotechnology activities mainly move around regional networks and the National Institute for Nanotechnology (NINT).

Globally, governments currently spend about US$ 10 billion per year on nanotechnology research and development. By the end of 2011, the total government funding for nanotechnology research worldwide was more than US$ 65 billion, which is expected to rise to US$ 100 billion by 2014. When figures for industry research and various other forms of private funding are taken into account, which were thought to have surpassed government funding figures as far back as 2004, it is estimated that nearly a quarter of a trillion dollars will have been invested into nanotechnology by 2015 (Cientifica 2011).

In terms of patenting, according to studies carried out by Statnano (2013), 27,350 patents had been published by the end of 2012 in United States Patent and Trademark Office (USPTO), among which 57 per cent were published by the US, giving the first rank to this country while Japan, Republic of Korea, Taiwan and Germany held the next ranks. India ranked 18th with 117 published patents at USPTO. In the same period, more than 13,350 nanotechnology patents were granted, which equaled 5.7 per cent of the total patents in the same year. In this ranking also, the US ranked first, followed by Japan, Republic of Korea, Taiwan and Germany.

In terms of publications, Centre for Knowledge Management of Nanosciemce and Technology's (CKMNT) analysis revealed that the top 10 countries in nano S&T publications for the year 2012 were China, USA, South Korea, India, Germany, Japan, France, Iran, UK and Spain. During the past three years, China has surpassed US in these publications and has become the single largest contributor of scientific publications worldwide in the nano science and technology (Nanotechnology Now 2013).

As far as nanotechnology market effect is concerned, a recent research study, "Nanotechnology Market Outlook 2017" by RNCOS, a business consulting service firm, has identified that the global nanotechnology industry has been growing at a rapid pace with rising applications in sectors like drug delivery, diagnostic devices etc. In addition, market trends like nanotechnology based thin film solar cells with high efficiency, nanomaterials with higher strength, robust growth in nanofibers and nanomedicine market, etc., are booming growth in this industry. Considering the above factors, the global nanotechnology market is anticipated to grow at a CAGR of around 19 per cent during 2013-2017 (RNCOS 2013).

The nanotechnology market prospects, as envisaged by various market research bodies, are forecasted to be very positive; Lux Research, National Science Foundation (NSF) and Cientifica projected these to be around a trillion dollar business by 2015.

3. Importance for Developing Countries

As, there are many wider applications of nanotechnology, experts have reckoned a list of top ten nanotechnology application areas which are of concern for developing countries such as India with respect to addressing UN Millennium Development Goals (MDGs) goals (Table 2).

Table 2: Applications of Nanotechnology with Examples

Sl. No.	Applications	Examples
1.	Energy storage, production, and conversion	• Novel hydrogen storage systems based on carbon nanotubes and other lightweight nanomaterials • Photovoltaic cells and organic light-emitting devices based on quantum dots • Carbon nanotubes in composite film coatings for solar cells • Nanocatalysts for hydrogen generation • Hybrid protein-polymer biomimetic membranes
2.	Agricultural productivity enhancement	• Nanoporous zeolites for slow-release and efficient dosage of water and fertilisers for plants, and of nutrients and drugs for livestock • Nanocapsules for herbicide delivery • Nanosensors for soil quality and for plant health monitoring • Nanomagnets for removal of soil contaminants
3.	Water treatment and remediation	• Nanomembranes for water purification, desalination, and detoxification • Nanosensors for the detection of contaminants and pathogens • Nanoporous zeolites, nanoporous polymers, and attapulgite clays for water purification • Magnetic nanoparticles for water treatment and remediation • TiO_2 nanoparticles for the catalytic degradation of water pollutants

Table 2 continued...

Table 2 continued...

4.	Disease diagnosis and screening	• Nanoliter systems (Lab-on-a-chip) • Nanosensor arrays based on carbon nanotubes • Quantum dots for disease diagnosis • Magnetic nanoparticles as nanosensors • Antibody-dendrimer conjugates for diagnosis of HIV-1 and cancer • Nanowire and nanobelt nanosensors for disease diagnosis • Nanoparticles as medical image enhancers
5.	Drug delivery systems	• Nanocapsules, liposomes, dendrimers, buckyballs, nanobiomagnets, and attapulgite clays for slow and sustained drug release systems
6.	Food processing and storage	• Nanocomposites for plastic film coatings used in food packaging • Antimicrobial nanoemulsions for applications in decontamination of food equipment, packaging, or food • Nanotechnology-based antigen detecting biosensors for identification of pathogen contamination
7.	Air pollution and remediation	• TiO_2 nanoparticle-based photocatalytic degradation of air pollutants in self-cleaning systems • Nanocatalysts for more efficient, cheaper, and better-controlled catalytic converters • Nanosensors for detection of toxic materials and leaks • Gas separation nanodevices

Table 2 continued...

Table 2 continued...

8.	Construction	• Nanomolecular structures to make asphalt and concrete more robust to water seepage • Heat-resistant nanomaterials to block ultraviolet and infrared radiation • Nanomaterials for cheaper and durable housing, surfaces, coatings, glues, concrete, and heat and light exclusion • Self-cleaning surfaces (e.g., windows, mirrors, toilets) with bioactive coatings
9.	Health monitoring	• Nanotubes and nanoparticles for glucose, CO_2, and cholesterol sensors and for *in-situ* monitoring of homeostasis
10.	Vector and pest detection and control	• Nanosensors for pest detection • Nanoparticles for new pesticides, insecticides, and insect repellents

Source: PLoS (2005).

Apart from the applications mentioned in Table 2, nanotechnology is being used in textiles, ICT, cosmetics and personal care products, electronics and home appliances, defence, etc., all across the world. All these applications of nanotechnology can be leveraged for social and economic development of the developing countries such as India.

4. Evolution of Nanotechnology in India

The 9th Five-Year Plan (1998-2002) had mentioned for the first time that national facilities and core groups were set up to promote research in frontier areas of S&T which included superconductivity, robotics, neurosciences and carbon and nano materials. Planning Commission supported number of such R&D programmes under basic research (GOI 1998).

However, the thrust came with the launch of “Programme on Nanomaterials: Science and Devices” in 2000 by the Department of Science and Technology (DST). DST launched special initiative to generate and support some end-to-end projects leading to tangible processes, products and technologies after realising the importance of nanomaterials and their far-reaching impact on technology (DST 2001).

In 2001-2002, the DST set up an Expert Group on “Nanomaterials: Science and Devices”. The Government identified the need to initiate a Nanomaterials Science and Technology Mission (NSTM) in the 10^{th} Five Year Plan (2002-07) after taking into consideration the developments in nanotechnology. A strategy paper was evolved for supporting on a long-term basis both basic research and application oriented programmes in nanomaterials (DST 2001).

The Tenth Five Year Plan (2002-2007) document identified various areas for mission mode programmes such as technology for bamboo products, drugs and pharmaceutical research, instrument development including development of machinery and equipment, seismology, and also nano science and technology (GOI 2002).

Subsequently, the National Nanoscience and Nanotechnology Initiative (NSTI) was launched in October, 2001 under the aegis of the Department of Science and Technology of the Ministry of Science. The motive of launching NSTI in 2001 was to create research infrastructure and promote basic research in nanoscience and nanotechnology. It focused on various issues relating to infrastructure development, basic research and application oriented programmes in nanomaterial including drugs/drug delivery/gene targeting and DNA chips. Nanotechnology was heralded as a revolutionary technology with applications in almost every aspect of life.

Overwhelmed by the promising prospects of nanotechnology applications and in order to further enhance the visibility of India in nano science and technology, a Nano Science and Technology Mission (NSTM) was envisioned to give desired thrust to research and technology development in this area (DST 2006). The Eleventh Five-Year Plan (2007-2012) categorically mentioned projects to create high value and large impact on socio-economic delivery involving nano material and nano devices in health and disease. The generous Eleventh Five Year Plan Budget allocation of Rs. 1000 crore was earmarked for the Nano Mission when it was launched in 2007 (GOI, 2007).

Accordingly, on 3 May 2007, a Mission on Nano Science and Technology (Nano Mission) was launched by the DST to foster, promote and develop all aspects of nanoscience and nanotechnology which have the potential to benefit the country. The Mission is steered by a Nano Mission Council (NMC) under the Chairmanship of Prof. CNR Rao. The technical programmes of the Nano Mission are also being guided by two advisory groups, viz. the Nano Science Advisory Group (NSAG) and the Nano Applications and Technology Advisory Group (NATAG). The primary objectives of the Nano-Mission are:

- Infrastructure Development for Nano Science and Technology Research
- Public Private Partnerships and Nano Applications and Technology Development Centres
- Human Resource Development
- International Collaborations
- Academia-Industry partnerships to be nurtured under these programmes (DST 2008).

In the Twelfth Five Year Plan (2012-2017) too, the government gave its approval for continuation of the Mission on Nano Science and Technology (Nano Mission) in its Phase-II at a total cost of Rs. 650 crore. The Nano Mission, in this new phase, would make greater effort to promote application-oriented R&D so that some useful products, processes and technologies also emerge. It will continue to be anchored in the Department of Science and Technology and steered by a Nano Mission Council chaired by an eminent scientist (PIB 2014).

5. Nanotechnology Research, Development and Innovation in India: Major Actors

The government has played a pioneering role in promoting nanotechnology R&D in India. It has taken many initiatives to foster and promote R&D in India through several of its departments. Many schemes/programmes have been launched for infrastructure and human resource development. The government has also undertaken manybilateral/multilateral/regional initiatives with many countries to promote nanotechnology research, development and innovation (RDI). It has also encouraged PPP model to encourage nano-based product development. The main departments which have been involved in nanotechnology RDI in India are discussed below.

Department of Science and Technology (DST): DST is the nodal agency in the Indian nanotechnology innovation system. It has since 1980s launched may programmes/schemes to foster R&D on miniature-scale and on nano-scale. Some such major programmes/ schemes are as follows:

- Intensification of Research in High Priority Areas (IRHPAS): a programme launched by the DST during the sixth Five Year Plan (1980-1985).
- The committee on Emerging Technologies was set up in 1997 to fund research for three years. Science and Engineering Research Council (SERC) also initiated a programme on nanocrystalline material.
- The National Programme on Smart Materials (NPSM), which is a five year programme funded for Rs. 90 crore, was launched jointly by the five government departments, viz. Defence Research and Development Organisation (DRDO), Council of Scientific and Industrial Research (CSIR), Department of Space

DOS, DST and Ministry of Information Technology (MIT) in the year 2000.

- Nano Science and Technology Initiative (NSTI), launched by the DST, in 2001, focused on various issues relating to infrastructure development, basic research and application oriented programmes in nanomaterial including drugs/drug delivery/gene targeting and DNA chips. It gave way to Nano Mission in 2007.
- The Nano Science and Technology Mission (NSTM) – an umbrella programme – was launched in the year 2007 to promote R&D in this emerging area of research in a comprehensive fashion. An allocation of Rs. 1000 crore for five years was made. The main objectives of the Nano Mission are: basic research promotion, infrastructure development for carrying out front-ranking research, development of nano technologies and their applications, human resource development and international collaborations. Through the NSTI and later Nano Mission, the DST has sponsored many nanoscience and nanotechnology projects across the country in various universities and research centres/laboratories. However, on analysing the budget of DST in the period 2001-2013, it is found that theDST has invested around Rs. 965 crore in the Nano Mission since its inception in 2007. The year-wise allocations are shown in Figure 1.

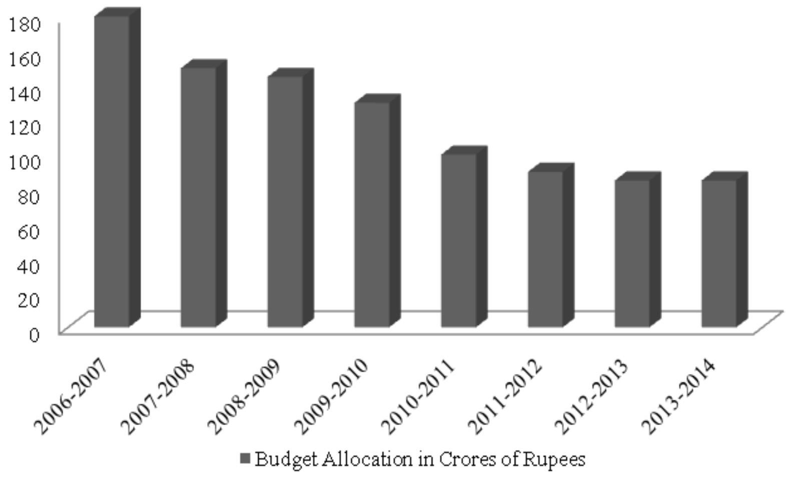
From Figure 1, it can be easily made out that over a period of time the budget allocation for the Nano Mission has decreased considerably. In fact, it is now half of what it was at the time of its inception in 2007. This is a disturbing trend as far as development of an effective Indian nanotechnology innovation system is concerned. The study finds that the share of Nano Mission's budget in the total DST's budget has declined from around 10 per cent in 2007 to just 3 per cent in 2013.

At this juncture, it would be appropriate to give a comparative figure of the US Nano R&D funding during 2002-2013, which is far more than what the Indian government has invested. The US government had allocated US$ 16.9 billion during financial years 2002-2013 for nano R&D (Bangalore India Nano 2013).

For developing physical infrastructure, the DST has established Units on Nano Science, Centres for Nanotechnology, Centre of Computational Materials Science and Thematic Units of Excellence on Computational Material Science in various universities and government research centres/laboratories across the country.

As far as human resource development is concerned, the Nano Mission has launched PG programmes (M.Sc and M.Tech in Nanoscience and Nanotechnology) at various universities and colleges all across India and till 2012-13, 17 such courses were being run by it in the country.

Figure 1: DST Nano Mission Funding in the Period 2006-2013



Source: DST Budget Documents (analysed by author).

For nurturing the Public-Private-Partnership (PPP) activities, the DST had sanctioned a few nanotechnology projects (DST 2008). The notable among them are:

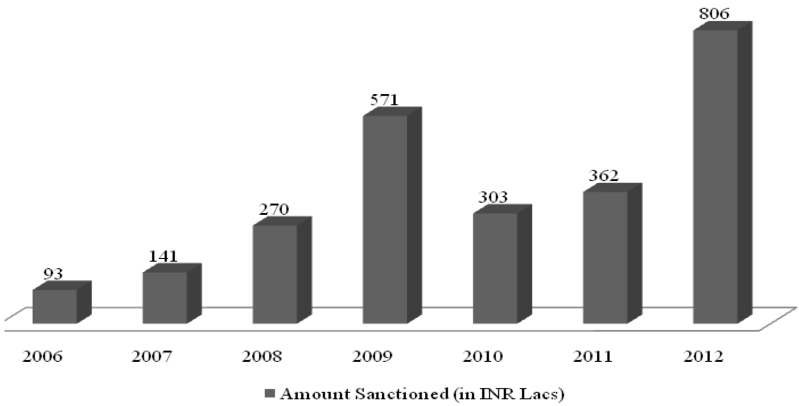
- Nano Functional Materials Technology Centre (NFMTC) at the Institute of Technology Madras, Chennai: The Centre is working on cost effective method for the production of oxide ceramic powders of nano size; consolidation and sintering of nanocrystalline oxide powders for the production of bulk ceramics; nanocrystalline diamond (NCD) films/coatings on die-inserts and plugs to increase wear-resistance and durability; cost effective production of large scale and highly pure random and aligned carbon nanotubes (CNT); and nanostructured multi-drug-delivery system for hard tissue applications and CNTs for laser based treatment of cancer by photodynamic therapy. The participating industries are Murugappa Chettiar Group and Orchid Chemicals and Pharmaceuticals.
- Development of high performance rubber nanocomposites for tyre engineering: This project being implemented at Mahatma Gandhi University, Kottayam envisages the development of novel technologies in tyre engineering band on nanosize fillers in collaboration with Apollo Tyres.
- Research programme on Smart and Innovative Textiles (SMITA) at the Indian Institute of Technology, Delhi: Smart textile is an emerging area. The programme aims at fundamental understanding of generation of novel materials such as nanofibres, nanofinishes, and encapsulated phase change materials with desired characteristics; investigation of novel methods that are suitable for integrating above materials to textile substrates; fundamental understanding of the effect of the above materials and methods on functionalisation of textile structures for developing smart textile; development of technology for upscaling the above processes for industrial benefit and creating new products for high value addition in the textile sector and creating comprehensive expertise and competence within the country by man-power training and enhancement of technical knowledge base. The participating industries are Resil

Chemicals, Bangalore; Purolator India Limited, Gurgaon; and Pluss Polymers Private Limited, Delhi.

- Support to Nanotechnology Business Incubator (NBI) at NCL: The NBI has nurtured activities by seven start-up companies on items like – computational modelling of flow and chemical processes, therapeutic potential of biotechnologically engineered antibodies, ocular and maxillofacial implants, and 12 start-up companies are under incubation presently as Resident Incubates on items like maxillo-facial surgery, organic chemical synthesis, etc., (DST 2013).

As far as the international collaborations in the field on nanoscience and nanotechnology research, development and innovation are concerned, the DST has launched bilateral joint-research projects with more than 25 countries and multilateral research projects with regional/multilateral bodies such as EU, BRICS and IBSA. The DST has been actively promoting international collaborations through bilateral joint research-projects over a period of time. The investment made by DST has remarkably increased almost 10 times in the period 2006-2012 (Figure 2).

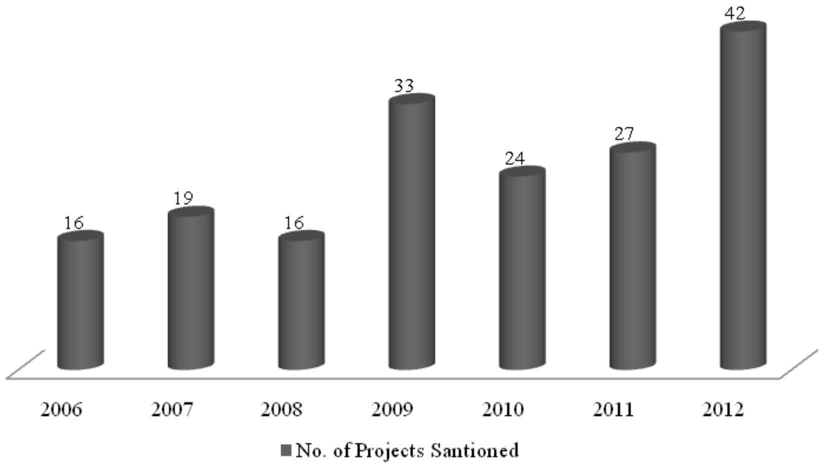
Figure 2: DST Investments on International R&D Collaborations in Nanotechnology



Source: Author's own analysis.

It is also seen that the number of international joint-research projects on nanoscience and nanotechnology increased almost three times in the same period 2006-2012 (Figure 3).

Figure 3: DST Sanctioned International Projects on Nanoscience and Nanotechnology



Source: Author's own analysis.

These international collaborative projects cover a range of nanoscience and nanotechnology basic and applied research in areas having diverse applications such as:

- Healthcare/medicine/drug delivery
- Sensors
- Energy storage in batteries
- Solar energy
- Fuel cells
- Other areas of use of nano-materials such as thin films, carbon nanotubes, nano composites, etc.

Department of Biotechnology (DBT): The DBT is basically active in the area of nano biotechnology R&D. It has been engaged in promoting interdisciplinary research, fostering innovations and promoting development of translational research in various areas of nano biotechnologies including developing new therapeutics, diagnostics for early disease detection and imaging, design and development of tissue specific drug delivery, medical devices, and fabricating sensors for detection of chemicals and pathogens in food and crop.

In the biotechnology sector, the government, while realising the importance of nanotechnology applications in biotechnology, sees nano-bio industries as a new-generation biotech industries (GoI 2012). In the period around 2007, the Department of Biotechnology (DBT) initiated a programme on nanobiotechnology. Since then, this Programme has promoted basic R&D in the following areas (DBT 2008):

- Nanotechnology for food/agriculture: weed utility, nanosensor for crop protection, pesticide delivery vehicles, nanocides, smart packaging, sensors for detecting pathogens and chemicals in food and crop, etc.
- Nanotechnology for animal husbandry: biodegradable nanoparticles for drug delivery, etc.
- Nanotechnology for environment management: biosysnthesis of nanoparticles, treatment of industrial effluent, waste management, etc.
- Nanotechnology for healthcare/medicine/drug delivery: Drug delivery system, disease diagnosis, cancer and TB therapy, scaffolds, medical devices, implants and imaging, etc.
- Nanotechnology in other allied areas such as bioengineering, water filtration, etc.

Department of Electronics and Information Technology (DeITy): The DeITy has established Centre for Materials for Electronics Technology (C-MET) at Pune, Hyderabad and Trissur. These centres are involved in nanotechnology R&D activities, particularly in nanomaterials. They provide matrials, fabricating facilities, prototyping facilities, technology transfer and consultancy services for the interested entities including industries.

As far as, the nanotechnology application in the information and communication technology (ICT) industry sector is concerned, it has been mentioned as key emerging vertical market for the Information Technology Enabled Services (ITES) industry (GoI 2007). The prospect for nano-info-bio convergence has also been highlighted in recent times (GoI 2007).

The major thrust of nanotechnology-led path dependency is seen in the electronics industry sector, particularly in the semiconductor industry sector in India. To make up for missing the semiconductor bus in 1980s, the government is keen to harness the potentialities that nanotechnology can provide for revamping the electronics manufacturing industry sector. Some of the key schemes/policies that have been launched in this direction are as follows:

- DeITy started the Nanotechnology Development Programme (NDP) in 2004 to create infrastructure and promote basic research in the areas of nanoelectronics and nanometrology in India. The mission was to develop knowledge base in the electronics materials and their processing technology for the Indian industry (DeITy 2006). From 2004 to 2011, a total of US$ 100 million has ben invested in the nanoelectronics R&D by DeITy. In the programme on nanotechnology initiative, the budget of US$ 20 million per year has been earmarked for research and innovation in nanoelectronics sector (Ramaraju 2012).

- A special package was initiated to fuel further growth of semiconductor manufacturing. This Special Incentive Package Scheme (SIPS) for Semiconductor Fabrication and Micro and Nanotechnology Manufacture Industry was launched by the DeITy in 2007 to attract investments for setting up semiconductor fabrication and other micro and nanotechnology manufacturing industries in India. It has received very positive response from prospective investors (DeITy 2011).
- In the whole scheme of creating globally competitive Electronics System Design and Manufacturing (ESDM) industry in India, the nano-electronics has been identified as a key element to meet the country's needs and serve the international market (DeITy 2013). The National Policy on Electronics (NPE) launched in 2012, talks about the need for a separate sector specific strategy. One of the important objectives of NPE is to achieve a turnover of about US$ 400 billion by 2020 involving an investment of US$ 100 billion, enhance exports from US$ 8 billion to US$ 80 billion and employment to around US$ 28 million by 2020 (DeITy 2014).
- A Nanoelectronics Innovation Council has also been set up recently by DeITy in 2012. The scope of the Council includes the entire electronics systems hardware infrastructure enabled by nanoelectronics technology (Electronics Bazaar 2012).
- Electronics Development Fund, involving US$ 2 billion, has been proposed by DeITy to promote innovation, product development, commercialisation of products in electronic system design and manufacturing (ESDM), nanoelectronics and IT sectors.

Department of Industrial Policy and Promotion (DIPP): DIPP established a Nano-Manufacturing Technology Centre (NMTC) and Academy of Excellence for Advanced Manufacturing Technology (AEAMT) at the Central Manufacturing Technology Institute (CMTI) in Bangalore.

Department of Industrial and Scientific Research: The DISR through its autonomous body, the CSIR provides for projects funding as well as various grants and fellowships and help in S&T and human resource development in the basic and applied sciences including that in nanoscience and nanotechnology. The CSIR has 39 laboratories established all across the country. They are engaged in R&D in biological, chemical, physical and engineering fields. Nano-related R&D is also being carried out in some of these labs.

6. Nanotechnology and Regulation: Global and Indian Perspective

The scale of nanotechnology's operation has raised concerns over nanotechnology risk and safety aspects with respect to environment and health safety (EHS) as well as its ethical, legal and social implications (ELSI). The World over, countries are vying to establish a regulatory framework to address these concerns. The initiatives in this regard comprise enacting new regulations or amending existing regulations/laws for nanotechnology; enforcing safety guidelines for researchers/workers in the laboratories in universities/research centres or companies; and establishing a global standard.

The European Union has also been active in the aspect of addressing these concerns. In a non-binding resolution, the European Parliament asked for tighter controls on nanotechnologies, in particular in the case of chemicals and materials, cosmetics, foods, occupational health and worker safety, environmental safety and waste. The most important among the steps taken is the initiative to revise REACH (Registration, Evaluation, Authorisation and Restriction of Chemicals). REACH regulates the use of chemical substances in Europe. In March 2008, the European Chemicals Agency (ECHA) established the Competent Authorities Sub Group on Nanomaterials (CASG Nano) for this purpose. The Sub Group published two technical guidelines and launched three projects in 2010 devoted to the application of REACH to nanomaterials, as well as the application of the related CLP regulation (classification, labelling and packaging of substances and mixtures). Regarding chemicals, the way nanomaterials are considered in REACH will strongly influence regulatory actions at national level, in particular in countries such as France, Germany, Austria, Belgium, and Italy whcih are considering introducing notification and registration mechanisms for nanomaterials (Mantovani *et al.* 2011).

In the US, the Environmental Protection Agency (EPA), under the Toxic Substances Control Act (TSCA), has been mandated to regulate nanomaterials. A task force on nanotechnologies has been active within the Food and Drug Administration (FDA) since 2007. The general approach to nanoregulation of FDA is that the existing regulation adequately covers nano forms of substances, though a careful review is generally devoted to nanotech products (Mantovani *et al.* 2011).

In Canada and Australia, environmental health and safety (EHS) and regulatory issues are receiving increasing resources within their national strategies for nanotechnologies, and the need to adopt a precautionary approach is explicitly stated. There is a growing involvement of authorities in different sectors that are working to develop regulatory, product-specific guidance documents for nanomaterials. The lack of a definition of nanomaterials is considered one of the key gaps to enable regulatory actions.

In Japan, the Ministry of Economy, Trade and Industry (METI), since 2008, has supported a voluntary gathering initiative related to risk management of nanomaterials at industry level. Research reports on occupational health and safety (OHS) issues of nanomaterials have been published by the National Institute of Occupational Safety and Health Japan (JNIOSH).

The Republic of Korea is developing the National Nano-safety Strategic Plan (2011-2015). Moreover, a specific Risk Management

Platform Technology for Nanoproducts is also at development stage and aims at providing a certification system for nano-related products. Several research programmes on EHS and ELSI are also in progress.

In Taiwan, within the framework of their Strategic Plan for Responsible Nanotechnology (2009-2014), the Nanomark Certification System has been active since 2004. This is a voluntary reporting and certification scheme that aims to increase public confidence in nanotechnology products.

In Thailand, nanosafety is among the priorities of the national policy on nanotechnologies. A strategic plan on safety and ethical issues is expected to be proposed to the government by the National Nanotechnology Center. This will include plans for the creation of an industrial standards certification for nanotechnologies related products (called NanoQ) (Mantovani *et al.* 2011).

The International Standards Organisation (ISO) Technical Committee (TC) 229, in conjunction with many national standards bodies, has been directing activities on nanotechnologies standards since 2004. The ISO TC 229 is organised into four working groups that focus on issues that are crucial for the development of an effective regulation for nanotechnologies-related products, viz. terminology and nomenclature; measurements and characterisation; health, safety, and environment; and materials specification. The Bureau of Indian Standards (BIS) is an active participating member of ISO TC/229 Committee which is presently engaged in devising Nanotechnology Standards. Till date, about 35 such standards have been published and some are in review stage.

Regarding safety of workers/researchers in laboratories, a number of countries require manufacturers of industrial chemicals, pharmaceuticals, veterinary drugs, pesticides, cosmetic products, food products, feed additives, etc., to establish through data that use of these products does not pose any hazards to human health and the environment. Non-hazardous nature needs to be established through studies and data, which is to be examined by the regulatory authorities of the concerned countries.

In India, the issue of nanotechnology risk regulation has been raised in terms of the concerns related to human health safety, environmental pollution, toxicity and towards general societal impacts relating to labour dislocation and livelihood disruption. Regarding the regulatory aspects many researchers are of the view that the government is very lax in establishing a regulatory body to foresee the safe development and commercialisation of nanotechnology products (Chowdhury 2006; Sarma 2011; Jayanthi *et al*. 2012). Few others have also raised the issue of labelling of nano-based products to enable people make an informed choice. In fact, on the sidelines of an International Conference on Nano Science and Technology (ICONSAT) in 2010 itself, Prof. CNR Rao, Nano Mission Council Chairman, said that 'as Indian industries are coming with various nanotechnological products including water filters, biomedical products, chemicals, cosmetics and paints, we are in the process of forming a regulatory body for the nanotechnology to regulate the products for the safety and benefit of the society'(Business Standard 2010).

Various existing Indian laws/regulations that need relevant and timely interventions/changes to encompass nanotechnology related consequences can be classified into the following categories (TERI 2010):

- Production and Marketing: Drugs and Cosmetics Act, 1940, National Pharmacovigilance Protocol, Medical Devices Regulation Bill, and Insecticides Act, 1968.
- Occupational Health and Safety: Factories Act, 1948 and OHS under other legislation.
- Environmental Risk Management: Pollution control laws, Environment Protection Act, and Public Liability Insurance Act.

- Waste Disposal: Factories Act, Hazardous Material (Management, Handling and Transboundary Movement) Rules 2007, Bio-Medical Waste (Management and Handling) Rules 1998, Municipal Solid Wastes Rules 2000.

As of now, there has been no effort made to streamline these acts/rules in order to address peculiarities that nanotechnology carries with itself.

However recently, the DST has made efforts made towards establishing of a regulatory system. The Nano Mission has organised national dialogues to promote R&D in development of standards for nanotechnology and for laying down a National Regulatory Framework Road-Map for Nanotechnology (NRFR-Nanotech) (PIB 2014).

It is aptly to quote here that so far there are no nano-specific rules or regulations in any government department or ministry, be it Environment Ministry or Health Ministry or Labor Ministry or Law Ministry. The deliberations have been going on to whether incorporate nano-specific concerns within the existing rules and regulations or create new ones exclusively dealing with nanotechnology.

According to the NISTADS Report (2012), it is argued that: “The multifaceted dimensions and implications of nanotechnology do not fit into the compartments delineated by the present regulatory framework in India. An effective risk governance system is urgently required both because of the inadequate picture of present nanotechnology regulatory scene and because of the perplexities presented by technological advancements.”

According to another researcher, “While leading nanotechnology nations are debating on the best strategy to ward off risk, Indian government has so far adopted a “learn by doing” approach in nanotechnology development. However, it is high time India's science and technology research bodies showed some seriousness towards nanotechnology risk governance." (Jayanthi *et al.* 2012)

On the experience of debates on GM, nuclear plant and nanomaterials in India, Chaturvedi (2013) very rightly observes that 'it is high time that we, as a society, develop institutional mechanism for technological assessments where, along with the safety aspects, knowledge streams from the social sciences are brought in to assess social and economic implications…We ought to explore the ways in which public influences the policy-making process'.

7. Conclusion

The development of nanotechnology in India has been mainly conceived and continued on the premise that this new and emerging technology has huge potential to help the country address societal challenges such as provision of drinking water, healthcare, etc., and simultaneously achieve economic gains through growth in the nanotech-based industrial sector. There have been various concerted efforts since early 2000s by the government to foster and promote nanotechnology in India. The Plan documents and various initiatives taken by various departments/ministries have placed much emphasis on this technology. The infrastructure development for basic research and human resource development has been the prime focus in the first phase of such initiatives (2007-2012), which is basically the first phase of Nano Mission. In the second phase, which begins with the Twelfth Plan period, i.e. 2012-2017, the focus would be on product development and commercialisation for markets and consumers. In addition to this, there have been efforts to establish a regulatory framework at national level for addressing the risk and safety aspects of nanotechnology. The world over, there have been serious efforts taking place in this regard and this is the high time that India too come up with a framework to ensure safety of humans and environment and minimise any unintended consequences out of the use of nanotechnology. The multilateral/bilateral cooperation play a major role in promoting cutting-edge basic R&D by providing Indian scientists access to sophisticated equipment/facilities in advanced countries. India's early involvement with various international/inter-governmental organisations, such as International Standards Organisation (ISO), Organisation for Economic Cooperation and Development (OECD), and IRGC, for the development of standards, safe lab practices and risk governance is quite significant.

Endnote

[1] Sustaining technologies are those that improve the performance of established products through the current technology product paradigm (Kostoff *et al*. 2004).

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