Journal of Social Science for Policy Implications
June 2014, Vol. 2, No. 2, pp. 227-251
ISSN: 2334-2900 (Print), 2334-2919 (Online)

Published by American Research Institute for Policy Development

Exploring the Opportunities and Challenges in Nanotechnology Innovation in India

Azamat Ali[1] and Dr. Kunal Sinha[2]

Abstract

Nanotechnology is one of the emerging technologies of the 21st century. It is an interdisciplinary science domain with potential applications in biotechnology, computer science, electronics, communication, medical and food, energy production and new materials. It has generated wide interest and its impact on society is expected to be huge. Innovative aspects of such new technology have important implications for the economic growth of the nations. It has received much global interest and many national governments are making large investments in nanotechnology research and development (R&D) activities. The present paper is an attempt to explore the nanotechnology R&D in the area of energy, water, health,food and agriculture sector in India. It also highlights the outcome of nanotechnology in the publications and patent numbers, institutional players in nanotechnology policy in India and the environmental, health and safety issues of this emerging technology. The information and data have been collected from publicly available sources and cited accordingly.

Keywords:nanotechnology; Innovation;development; India;R&D

1. Introduction

Nanotechnology is considered as an emerging and converging technology (Roco and Bainbridge, 2002) that is said to be one of the key technologies of the 21st century.

1 Doctoral Fellow, Centre for Studies in Science, Technology and Innovation Policy, School of Social Sciences, Central University of Gujarat, Sector-30, Gandhinagar- 382030, Gujarat, India.
Phone: 9978475174, Email: azamatcug@gmail.com
2 Assistant professor, Centre for Studies in Science, Technology and Innovation Policy, School of Social Sciences, Central University of Gujarat, Gandhinagar- 30, India.
Email: kunalsinhajnu@gmail.com

It is a young domain and encompasses disciplines such as applied physics, materials science, physical chemistry, physics of condensed matter, bio-chemistry and molecular biology, and polymer science and engineering (Heinze and Bauer, 2007). It is a scale of technology, not a type, and it has applications in every economic sector, such as medicine, energy, industrial applications, materials science, engineering, electronics, communications, cosmetics, additives, coatings, food science, water purification, and agriculture. A nanometer (or nm) is one billionth of a meter and its scale generally represents between 1 and 100m.

These diverse sciences collaborate together in order to understand the specific properties of the nanoparticles and to contribute to the scientific knowledge and to make new medical devices, more resistant materials and more efficient transistors among (Bhat, 2005) an unlimited number of other possibilities that are likely to change a number of industries (Avenel et al., 2007). Scientists and researchers in the scientific disciplines aggressively got involved in the relevant research as a parallel way to boost nanotechnology competitiveness through academic research, and corporations have been directing their R&D activities towards the exploration of nanotechnology opportunities. It is expected to impact all industrial products by increasing their performance by orders of magnitude and reducing the cost significantly.

Global investments in science, technology and innovation are estimated at $1.2 trillion as of 2009. India's R&D investment is less than 2.5% of this and is currently under 1% of theGross Domestic Product (GDP) (GOI, 2013). The gross domestic product in India expanded 4.7% in the fourth quarter of 2013 (Trading Economics, 2014). Increasing Gross Expenditure on Research and Development (GERD) to 2% from the present 1% of the GDP in this decade by encouraging enhanced private sector contribution. The Union Cabinet of India has approved the Science, Technology and Innovation Policy (STIP) 2013 and the policy goal is to accelerate the pace of discovery, diffusion and delivery of science led solutions for serving the operational goals of India for faster, sustainable and inclusive growth. The policy also aims at positioning India among the top five global scientific powers by 2020 (GOI, 2013).

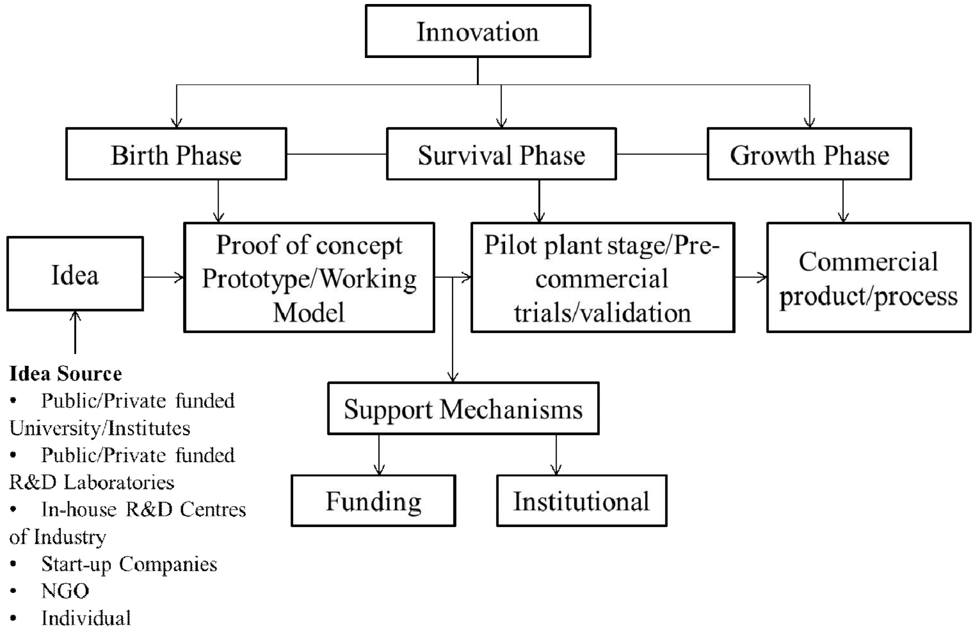
In this backdrop, the present paper has attempted to analyse the opportunities and challenges in the nanotechnology applications in the area of energy, water, health, and food and agriculture development in India.

The paper is divided into seven sections. Section onepresents some background information on both nanotechnology and India. Section two deals with the analytical framework. Section three analyses the research projects funded by India's Nano Mission and data on research publications and patent activities from 2001 to 2012. Section four deals with the opportunities in nanotechnologyR&D and commercialization in India. Section five deals with the policy and institutional environment for nanotechnology in India. Section sixdeals with the challenges associated nanotechnology applicationin India and finally section sevendeals with discussion and conclusion.

2. Analytical Framework

As a theoretical framework, this study is based on the idea of innovation system. Invention is the first occurrence of an idea for a new product or process, while innovation is the first attempt to carry it out in practice ((Fagerberg, 2005). The innovation system permits to study activities, actors, norms, rules, relationships, and other factors which influence innovation.The elements of the innovation system are focused upon universities, research institutions, technological institutes, and R&D laboratories (Lundvall and Borras,2005). In context of this, the Indian Nanotechnology innovation system can be assumed that it consists of three broad segments which enable the journey of an idea from human mind to market. The first phase is called the 'Birth Phase', where commercially viable idea gets converted into a workable process. The next phase is called the 'Survival Phase' wherein up-scaling of the process to the pre-commercial stage is done. The third phase is called the 'Growth Phase' wherein the pilot production is up-scaled to commercial production (Gupta and Dutta, 2005). A model of the Indian Nanotechnology Innovation System is illustrated in Figure 1.

Figure 1: Model of Indian Nanotechnology Innovation System



Source: Adapted from Gupta and Dutta, 2005.

The above framework has been used to provide a methodological background of the paper for the exploration of key elements of the Indian Nanotechnology innovation system.

3. Nanotechnology Development in India

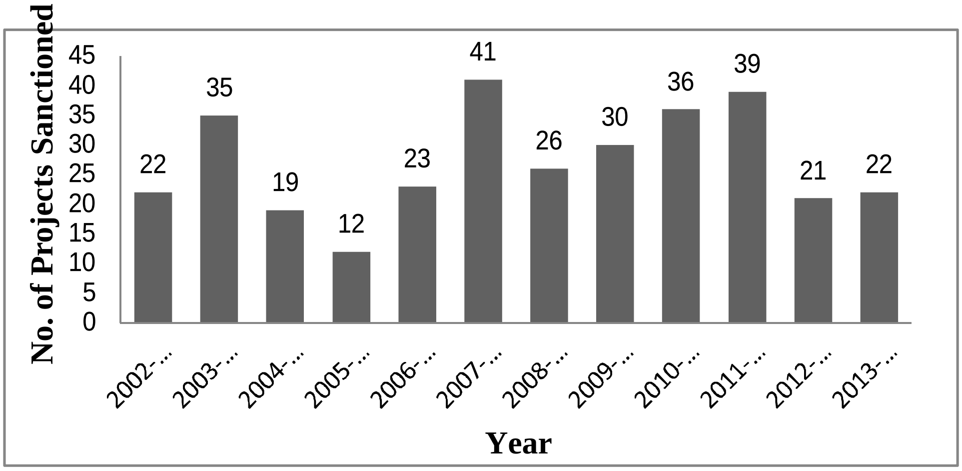
The Nanoscience and Technology Mission (NSTM) wasestablishedby theDepartment of Science and Technology (DST) during the 10th plan period(2002-2007) with an allocation of Rs. 60 crores (about 12 million USD) (GOI, 2002). During the 11th plan period(2007-2012) this program was upgraded through another major initiative known as ‘Nano Mission’ with a budgetary allocation of Rs. 1000 crore (about 250 million USD) for 5 years (GOI, 2007).The Union Cabinet has approved for the second phase of the nano mission in the 12th plan period (2012-2017) at a total cost of Rs. 650 crores (GOI, 2012).

Nano Mission aims to create the necessary innovation climate for nanotechnology in the country by strengthening basic research through funding support, creating centres of excellence, fund application oriented R&D projects, foster public private partnerships, organize international collaboration, education and training to researchers and professionals. Several other government funding agencies are engaged in, supporting nanotechnology in the national arena.

Department of Biotechnology (DBT) is one of the key stakeholders in nanotechnology and issued projects related to nanotechnology in the fields of agriculture, including nutrition and mitigating soil pollution, biology, nanobiotechnology, drug delivery systems and medicine for both fundamental research and technology development. Council for Scientific and Industrial Research (CSIR) is a network of 39 laboratories that engages in scientific and industrial R&D in nanotechnology in diverse areas. Department of Electronics and Information Technology (Deity) under the Ministry of Information and Communication Technology as well as the Indian Council of Medical Research (ICMR) under the Ministry of Health and Family Welfare is also supporting the expansion of nanotechnology in the areas of electronics and health respectively. The Ministry of New and Renewable Energy (MNRE) is supporting nanoscience and technology in India to utilize its potential in developing renewable energy sources like photovoltaic and fuel cells etc.

Defense Research and Development Organization (DRDO) a network of 50 laboratories under the Ministry of Defense as well as the Department of Atomic Energy (DAE) directly under the Government of India is contributing to the expansion of nanotechnology and Indian Council of Agriculture Research (ICAR) under the Ministry of Agriculture as well as the Ministry of Commerce and Industry has shown interest in engaging with nanotechnology in India. Associated Chambers of Commerce and Industry in India (ASSOCHAM), Federation of Indian Chambers of Commerce and Industry (FICCI) and the Confederation of Indian Industry (CII) are three major industrial associations involved in the promotion of nanotechnology in India. CII started its own nanotechnology initiative in 2002 to create a supporting environment for industry through knowledge exchange missions, awareness programs, workshops, market research and other range of services. Figure 2 exhibits the overview of projects supportedby the nano mission from 2002-2014.

Figure 2: Number of Projects Sanctioned by the Nano Mission



Source: DST, 2014.

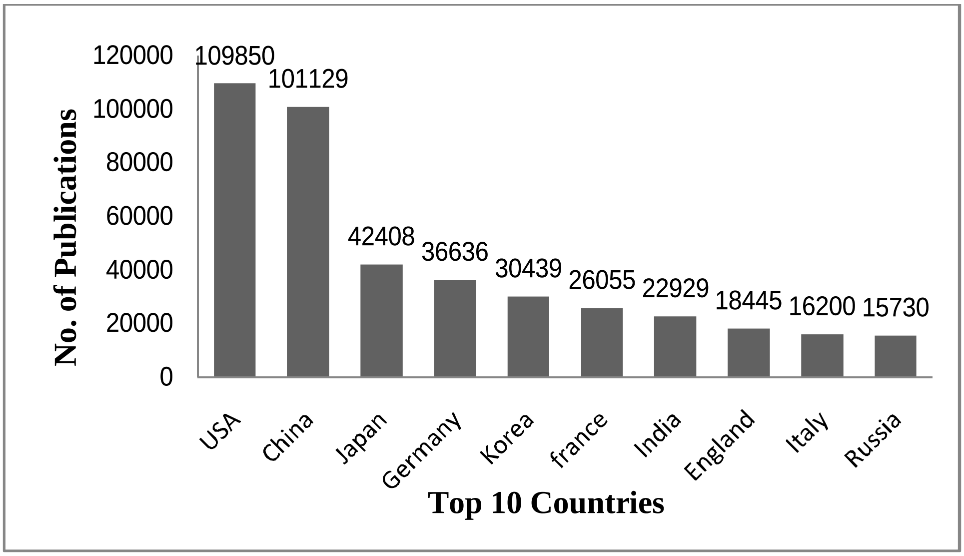
The preceding figure shows that 326 projects have been undertaken in the NSTI and NSTM science 2002.After a decline in the number of projects over two years of the NSTI & NSTM, the number has gone up again with 2007-2008 accounting for 25 per cent of the total number of projects sanctioned. Supports for these projects are oriented towards applied research and application development in the areas of health, agriculture, energy, environment etc. In the health sphere the projects supported have been in the broad areas of drug delivery, tissue engineering, gene therapy and nanotechnology methods for clinical oncology. Agriculture research looks at applications of nanomaterials in sericulture as well as in fisheries. Under energy, projects fund has been sanctioned include development of nanotubes for thermo-electric applications.

3.1. Indian Perspective of Nanotechnology Publications and Patents

Research and development (R&D) investments are indicators for the main inputs into science based innovation while R&D only covers one aspect of technological change and innovation. Publication and patent data provide complementary indicators for research and development activities, although capturing intermediate outputs (OECD, 2008).

Publication aggregate for the complete period 2001-2012 shows USA accounting for 109850 papers (26% of the total world papers), China 101129 papers (24% of the total world papers) and India 22929 papers (6% of the total world papers) in nanotechnology field. Figure 3 summarizes the growth of nanotechnology research in India in terms of R&D publications compared to the top ten countries of the world. (2001-2012).

Figure 3: The Top 10 Countries in Nanotechnology Ranked by the No. of Publications (2001-2012)



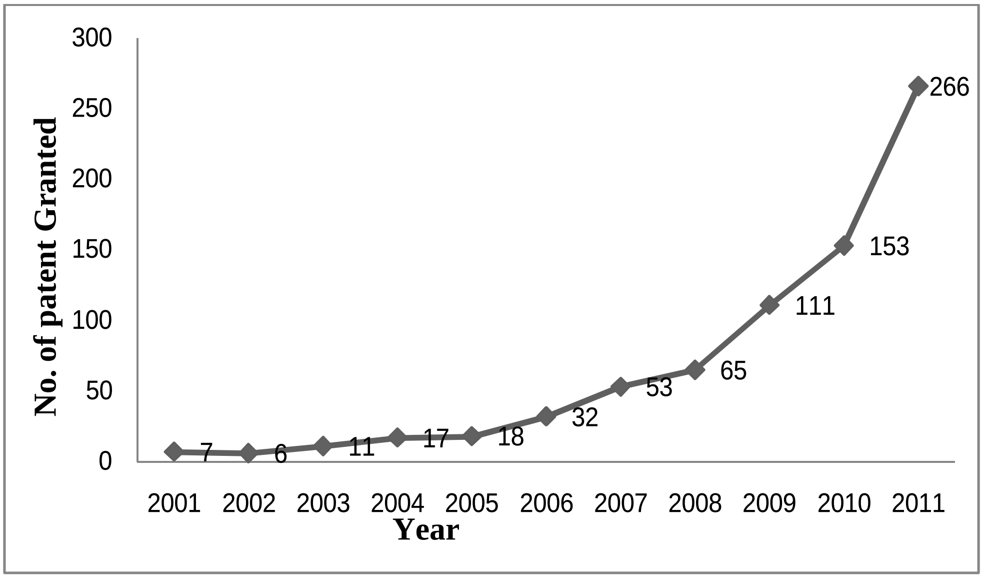
Source: Adapted from Purushotham, 2012.

The preceding figures show the number of nanotechnology papers published by authors in each country. The USA shows a remarkable presence in nanotechnology while China has the 2nd largest number of publications on nanotechnology. Other countries such as Japan has ranked 3rd and have a high impact on nanotechnology publication and France has 6th ranked that significantly impact on nanotechnology publications, while Russia has 10th ranked that appear to be devoted to nanotechnology. India has the 7thranks and contributes to about 6% of the global publications in nanotechnology and maintaining a global competitive because of significant government funding, educational initiatives and academic collaboration.

The top ten Indian institutes based on nanotechnology related publications are Jawaharlal Nehru Centre for Advanced Scientific Research (JNCASR) Bangalore, Indian Institute of Science (IISc) Bangalore, Bhabha Atomic Research Centre (BARC) Mumbai, Indian Association for the Cultivation of Science (IACS) Kolkata, National Physical Laboratory (NPL) New Delhi, Indian Institute of Technology (IITs) Kharagpur, Madras, Delhi, National Chemical Laboratory (NCL) Pune and University of Delhi.

The emerging field of nanotechnology is very active with respect to intellectual property rights with both universities and companies rushing to the patent office in record numbers to patent nanotechnology innovation. The highest number of nano patents worldwide is owned by the United States, China, Japan and Germany. In India, government institutions, industry, academic institutions and individual inventors have demonstrated an exponential increase in patenting activities during the period 2001- 2011 (see figure 4). This trend is visible with respect to patents filed abroad by Indian inventors.

Figure 4: Patenting Activity in Nanotechnology by Indian Inventors (2001-2011)



Source: Adapted from Purushotham, 2012.

The preceding figure indicates the growth of patenting activity in the field of nanotechnology by Indian inventors. It is observed that the intensity of patenting grew slowly during 2001 to 2005 but arose suddenly during 2006 to 2011, almost exponentially. The reason of increase in nanotechnology patents can possibly be attributed to the changed in the Patents Act 1970 in 2002 and then Trade Related Aspects of Intellectual Property Rights obligations for product patent from on 1 January 2005 as per product patents can be granted for chemicals, Agrochemicals and food. The major areas of patenting in the field of nanotechnology include its applications relating to drugs and pharmaceuticals, chemical sciences and technologies e.g. catalysis, colloid chemistry, separation and non-metallic elements and materials, analysing materials by determining their chemical or physical properties and methods or filters implantable into blood vessels.

4. Opportunities in Nanotechnology Innovation

There are millions of people worldwide continue to lack access to safe water, healthcare, reliable sources of energy, education, and other basic human development needs (UN Millennium project, 2005). Nanotechnology can play a major role to solve this problem. It involves a broad range of tools, techniques, and applications that manipulate materials at the nanoscale in order to produce novel properties that do not exist at larger scales. These solutions may include more sufficient, effective, and inexpensive water purification devices, medical diagnostic tests and drug delivery systems, energy sources, durable building materials and other products for developing countries.Both the public and private sectors in developed and developing countries are investing heavily in nanotechnology R&D. Developing countries such as China, South Africa, Brazil, and India have initiated national nanotechnology programs and expanding nanotechnology R&D capacities.

4.1. Water

Water availability has been a problem as a result of growing population, rapid urbanization, growing industrialization and expanding agriculture. Water and Poverty are closely linked and access to water resources has become widely associated with ensuring that basic human needs are met (Allhoff and Lin, 2011). It is mainly the poor of the world who depend directly on water and other natural resources for their livelihoods.85% of the world population live in the driest half of the planet.

783 million people do not have access to clean water and almost 2.5 billion do not have access to adequate sanitation. 6 to 8 million people die annually from the consequences of disasters and water related diseases (Water cooperation, 2013). There are many children miss school because neither their homes nor schools have adequate drinking water or sanitation facilities nor hundreds of millions of African, Asian, and Latin American families lose vital income from the lack of access to reliable drinking water and sanitation services (UN Millennium Project, 2005).

The World Bank estimates that 21% of communicable diseases in India are related to unsafe water (Water.org, 2014).Given the importance of clean water to people in developed and developing countries, various organizations are considering the potential application of nanotechnology to solve technical challenges associated with the removal of water contaminants. Technology developers and others claim that these technologies offer more effective, efficient, durable, and affordable approaches to removing specific types of pollutants from water (Todd et al., 2009). A range of water treatment devices that incorporate nanotechnology are already on the market and others are in advanced stages of development.These nanotechnology based products include nanofiltration membranes, zeolites, nano ceramic, clay, magnetic nanoparticles, polymer filters, nanocatalysts and nanosensors.Nanotechnology R&D in the water sector in India is mainly in the laboratory stage. Nano silver based products have been introduced in point of use water treatment systems which are given below:

- The International Advanced Research Centre for Powder Metallurgy and New Materials (ARCI), Hyderabad has developed a coating technology. The technology has been transferred to SBP AquatechPvt. Ltd. Hyderabad which will mass produce and market the candle filters (Vijaya et al., 2011).
- The nano silver activated carbon block has been developed in collaboration with Indian Institute of Technology, Chennai and is being marketed by Eureka Forbes as part of its new water purifier, Aquaguard Total Gold Nova (TERI, 2009).
- Indian Institute of Chemical Technology, Hyderabad has developed nano silver coated alumina catalyst using electrochemical method. These catalysts were found to be efficient for microorganism control in water (TERI, 2009).
- Rensselaer Polytechnic Institute in the US and Banaras Hindu University, Varanasi have devised a simple method to produce carbon nanotubes filters that efficiently remove micro to nanoscale contamination from water and heavy hydrocarbons from petroleum (RPI News and Information. 2004).

- Indian Institute of Technology (IIT), Kharagpur has developed synthesized iron oxide particles using chemical methods for arsenic removal from water (Vijaya et al. 2011).

Further, some of the companies are also engaged in the water treatment systems such as Tata Chemicals in India has developed candle filters embedded with magnetic nanoparticles. The manufacturing costs of these filters are expected to be as low as 5% of currently available and comparable technologies (Allhoff and Lin, 2011).

4.2. Energy

Energy is needed for economic growth, for improving the quality of life and for increasing opportunities for development. Access to basic, clean energy services is essential for sustainable development and poverty eradication, and provides major benefits in the areas of health, literacy, and equity.Some 1.4 billion people have no access to electricity and a billion more only have access to unreliable electricity networks. About 3 billion people depend on traditional biomass energy such as wood, crop, residues to meet their basic needs (UNDP, 2014). Access to modern energy services for cooking and heating, lighting and communications, and mechanical power for productive uses is a vast area of unmet need. The energy access challenge is particularly acute in the least developed countries, South Asia and Sub-Saharan Africa (UNDP, 2014). Some 600 million Indians do not have access to electricity and about 700 million Indians use biomass as their primary energy resource for cooking (Planning Commission, 2014).

Nanotechnologies provide the potential to improve energy efficiency across all branches of industry and to economically influence renewable energy production through new technological solutions and improved production technologies (Nanowerk, 2014). It provides essential improvement potentials for the development of both conventional energy sources such as fossil and nuclear fuels and renewable energy sources like geothermal energy, wind, sun, water, tides or biomass. Nanotechnology based involvements include photovoltaic cells and organic light emitting devices based on quantum dots as well as carbon nanotubes in composite film coatings for solar cells.It can enable cost effective solar and fuel cells with higher efficiency.

Safe and efficient ways to store hydrogen as well as improvements in batteries and super capacitors could also be made possible using nanomaterials (Sutter and Loeffler, 2006). Premier research institutes in India have been engaged in different areas of solar photovoltaic research with financial supports from MNRE and DST. The some of the R&D activity areas of the institutes are presented in table 1.

Table1: R&D in nanotechnology in energy sector in India

S.No.	Name of Institutes / University	Area of Research
1	Anna University, Chennai	Hybrid solar cell
2	Jawaharlal Nehru Centre for Advanced Scientific Research (JNCASR), Bangalore	Energy Storage device
3	Central Glass and Ceramic Research Institute (CGCRI),Kolkata	New Generation material development for photovoltaic arrays and solar cells
4	Indian Association for the Cultivation of Science (IACS), Kolkata	Hybrid solar cells with single-walled carbon nanotubes (SWNT) with Silicon (Si)
5	Indian Institute of Science (IISc), Bangalore	Carbon nanotube based super capacitor
6	University of Delhi, Delhi	New semiconductors as substitute for silicon in solar cells
7	National Physical Laboratory (NPL), New Delhi	Development of poly crystalline silicon and thin film solar cells
8	Indian Institute of Technology, Kanpur	Nanocrystalline silicon thin films
9	Jadavpur University, Kolkata	Efficient lighting systems for light emitting diode applications
10	Indian Institute of Technology, Bombay	Silicon-Lead Selenide (Si-PbSe) Quantum dots and organic solar cell

Source: Compiled from institutes and university websites

Currently, various government and private companies likeBharat Electronics Limited (BEL), Moser Baer Photo Voltaic Ltd (MBPV), Central Electronics Limited (CEL), Bharat Heavy Electricals Ltd (BHEL), Maharishi Solar Technology Private Limited, Tata BP Solar India Limited, signet solar India private limited and many others are making advanced multicrystalline and thin film solar cells and panels using indigenous and imported technologies.

4.3. Food and Agriculture

The rising cost of food and fuel is impacting on people all around the world and sadly we are on the brink of a humanitarian crisis with up to 1 billion people at risk of hunger because of food shortages (Oxfam, 2014). When faced with high food prices, many of the poorest families cope by pulling their children out of school and eating cheaper, less nutritious food, which can have catastrophic lifelong effects on the social, physical, and mental well-being of millions of young people (World Bank, 2014). One third of all child deaths globally are attributed to under nutrition, and up to 80 percent of our brain architecture develops during the first 1,000 days of life (World Bank, 2014).Frontier cutting edge technology like nanotechnology is one such emerging area in science and technology, which holds significant promise for agriculture and food systems (Roco, 2003) as well as improve the conditions of the poor (Juma et al., 2005).It can also help make food products cheaper and production more efficient and more sustainable through using less water and chemicals.

Agriculture and food security systems, disease treatment, sensors for pathogen detection, delivery methods, ecological protection, and education of the public and future workforce are the areas where nanotechnology could have a major impact on the science and engineering of agriculture and food systems (Shrivastava and Dash, 2012).The Government of India has accepted the importance of R&D in nanotechnology and it has been invested with the benefitsof such emerging technologies.A Planning Commission has called for the creation of a National Institute of Nanotechnology in Agriculture (NINA) under National Agricultural Research System. Industry like Indian chemical company Tata Chemicals is developing nanotechnology based crop specific, high value fertilizers to improve agricultural yields (Ghosh, 2006). Table 2 highlights some of the research and development that has been supported by agencies like DST and DBT at public funded institutes.

Table 2:R&D in Nanotechnology and Agriculture Sector in India

S. No.	Name of Institutes/University	Area of Research
1	Department Of Chemistry, Delhi University, Delhi	Development of controlled release nanoparticulate formulations for pesticides and insecticides
2	Indian Statistical Institute (ISI), Kolkata	Entomotoxic nanoparticle development: Insecticidal efficacy and Biosafety studies metabolomics and machine learning tools
3	University of Allahabad, Uttar Pradesh	Potential role of nanoparticles in plant pathogen detection in early stage and waste management
4	Madurai Kamraj University, Madurai	Preparation, characterization of nanoshells and their use to enhance plant growth
5	Institute of Minerals and Materials Technology, Bhubaneshwar	Nano Zinc oxide (ZnO) for smart packaging
6	Thiruvalluvar University, Vellore	Silver nanoparticles- potential applicationsin sericulture
7	Indian Institute of Chemical Technology, Hyderabad	Nano Zinc oxide for smart packaging
8	School of Chemical Sciences, University of Madras, Chennai	Potential use of nanoparticles for DNA vaccine in fish model to control bacterial and viral diseases

Source: Compiled from institutes and university websites

4.4. Health

Nanotechnology offers a range of potentials for health care and medicinal innovations, including targeted drug delivery systems, extended release vaccines, enhanced diagnostic and imaging technologies, and antimicrobial coatings. Some millions of people in countries like India or those in Sub-Saharan Africa is dying because of a lack of access to even basic health care, investing in cutting edge technologies is a ludicrous waste of money (Shetty, 2010). A group of scientists who have mapped out the uses of nanotechnology and the needs of global health argue that nanomedicine is relevant for the developing world.

They surveyed researchers worldwide and concluded that nanotechnology could greatly contribute to meeting the Millennium Development Goals for health. Specifically, the goals to reduce child mortality, improve maternal mortality and combat HIV/AIDS, malaria and other diseases (Salamanca et al., 2005; Shetty, 2010).

India has both its private and public sector working on nanotechnology R&D in the health sector. R&D in health in India has included developing nanocrystalline materials for bone replacement and drug delivery, biodegradable nanopolymer composites either for drug design and biomedical applications, nanoparticle mediated delivery of cancer cell lines, development of nanostructured materials for vascular grafts, nanocomposite materials for tissue engineering as well as generation of animations and nanosuspensions for pharmaceutical applications.There are numerous nanotechnology applications that are either currently on the market in India or are planned to be marketed over the coming years.

- Typhoid Detection Kit has been developed byDefense Research & Development Establishment (DRDE), Gwalior is using the nano sensor. According to an estimate the worldwide incidence of typhoid fever is 16 million cases annually and death rate is 6 lakhs individual per year worldwide (PIB, 2006). In India, the morbidity due to typhoid varies from 102 to 2219/100,000 population in different parts of the countries. In some areas typhoid fever is responsible for 2-5% of all deaths (PIB, 2006).
- University of Delhi, the Chemistry Departmenthas developed 11 patentable technologies for improved drug delivery systems using nanoparticles. Four of these processes have been granted U.S. patents. One of the important achievements at the initial stage of drug delivery research was the development of a reverse micelles based process for the synthesis of hydrogel and smart hydrogel nanoparticles for encapsulating water soluble drugs. This method enabled one to synthesize hydrogel nanoparticles of size less than 100nm diameter. This technology has been sold to Dabur Research Foundation in 1999 (PIB, 2006).
- The Central Scientific Instruments Organisation of India has designed a nanotechnology based TB diagnostic kit, currently undergoing clinical trials. This would cut both the cost and time required for TB tests, and also requires a smaller amount of blood for testing (Shetty, 2010).

- Centre for Research in Nanotechnology & Science (CRNTS) at the Indian Institute of Technology, Bombay has been focused on the use of nano magnetic materials in the form of magnetic fluids for hyperthermia treatment of cancer.

Private Companies such as Dabur Pharma Limited, Bilcare Research Ltd,Prakruthik Health care, Shasun Pharmaceuticals Ltd and Nanoparticle Biochem, Natco Pharma, Richmond Chemical Corporation, Vascular Concepts, and Lifecare Innovations Pvt. Ltd. are leading firms in India which are active in the different areas of nanotechnology research in health sector i.e. therapeutic, diagnostics and consumer health.

4.5. Commercialization of Nanotechnology in India

Globally, the nanotechnology industry is a billion dollar market. The global market size of the nanotechnology industry in 2011 was valued at nearly $ 20.1 billion and is projected to reach $48.9 billion in 2017 after increasing at a five year compound annual growth rate (CAGR) of 18.7% (BCC Research, 2012). An estimate by Lux research indicates that the number of nanotechnology products and workers worldwide will double every three years, achieving a $3 trillion market with 6 million workers by 2020 (Lux research, 2009).The Indian nanotechnology industry was valued at $100m in 2006 (Cygnus Research, 2007). It involved materials and manufacturing, electronics, IT based manufacturing, high speed process technologies, medicine and health, biotechnology and agriculture, environment and energy, aeronautics and space are the major areas. Leading Indian companies like Reliance, Tata Group,and Intel India, Mahindra and Mahindra are making investments in nanotechnology both for improving products their existing businesses and exploring other businesses for the next generation and have pumped in close to $250 million in domestic markets (Srivastava, 2007). Table 3 provides a list of some of the major nanotechnology based products commercialized by Indian companies and institution partnerships.

Table 3:Nanotechnology Based Products Commercialized by Indian Companies and Institution Partnerships

S. No.	Company	Name of the product/technology	Source of Technology
1	Eucare Pharmaceuticals Private Limited, Chennai	Nano bioceramics for dental, orthopedic and bone graft applications	National Metallurgical Laboratory, Jamshedpur
2	ABS Medicare Pvt. Ltd., Vadodara	A process for the manufacture of hydrogel wound dressing	Bhabha Atomic Research Centre, Mumbai
3	Cranes Software International Limited, Bangalore	Microelectromechanical systems (MEMS)	In-house
4	Lifecare Innovations Pvt. Ltd., Gurgaon	Liposomal based amphotericin B formulation (Fungisome)	Post Graduate Institute of Medical Education and Research, Chandigarh
5	Velbionanotech, Bangalore	Bio-nano chip and DNA based drugs	In-house
6	Centre for Advance Research & Development (CARD), Bangalore	Nano blaster to blast cancer cells in the human brain	In-house
7	Panacea Biotech, New Delhi	Smart hydrogel nanoparticles for drug delivery systems	In-house
8	Lifecare Innovations Pvt.Ltd., Gurgaon	Nanotechnology based drug delivery systems	University of Delhi
9	Dabur Pharma Ltd., New Delhi	Drug delivery systems for cancer treatment	University of Delhi
10	Bilcare Limited, Pune	Anti-counterfeiting security technologies for drugs (NonClonable)	In-house
11	Bharat Heavy Electricals, Bangalore	Metal oxide nano materials	In-house
12	Natco Pharma Ltd., Hyderabad	Nanotech based generic version of breast cancerdrug (Abraxane)	In-house
13	Monad Nanotech, Mumbai	Carbon Nano Tubes (CNTs)	In-house development
14	ICAN Nano, Kolkata	Nano paints	In-house
15	Tata Steel, Jamshedpur	Nano fluids	In-house

Sources: Collected from websites and annual report of the companies

5. Regulatory Players in Nanotechnology Applications in India

The regulatory governance framework for a technology refers to a number of aspects of the production and application of that technology (Susskind, 1996). The governance framework for nanotechnology development in India would ideally involve a host of playersat various national and international levels and institutions, including research bodies, promotional agencies, planning bodies, nodal ministries, other ministries, regulatory agencies, implementing agencies etc. performing different functions. For responsible governance of nanotechnology, it is essential to identify the roles of different players and stakeholders.The role of international level organization such as the World Health Organization (WHO) is to develop, establish and promote international standards with respect to food, biological,pharmaceutical and similar products. The International Risk Governance Council (IRGC) is an independent international organization. It is set up with the objective of helping the different stakeholders in understanding and management of emerging global risks that have an impact on human health and safety, the environment, economy and society at large. The International Organization for Standardization (ISO) is the premier international organization and fairly actives in engaging with aspects of material standardization of nanotechnology.

The Ministry of Science and Technology is the nodal ministry for the promotion of research and development in the area of technology and administers. It functions through three departments DST, DBT and Department of Scientific and Industrial Research (DSIR). DST is the most instrumental agency within the government for encouraging nanotechnology development and application through both financial and institutional support. It is working with Nano Mission for development of nanotechnology in India. Nano Mission includes two advisory groups, a) Nano Applications and Technology Advisory Group (NATAG), and b) the Nano Science and Advisory Group. Support for risk research in the country has mainly come from the DST run programs and DBT support for research on the application of nanomaterials in biological sciences.

Institutes and laboratories under the CSIR) such as the Central Drug Research Institute (CDRI) and the Indian Institute of Toxicology Research (IITR) are engaged in essential and specific research fundamental for nanotechnology governance.

The Ministry of Commerce is an important actor in protecting intellectual property rights in the field of nanotechnology and being responsible for addressing the complexities of nanotechnology in the current patent legislation. The Ministry of Health and Family Welfare (MoHFW) supports toxicological studies relating to nanoparticles in health applications through the ICMR. It involved in governance of nanotechnology applications in the health sector through its Directorate General of Health Services (DGHS), under which the Central Drugs Standard Control Organization (CDSCO) is situated. Institutionally, MoHFW is in charge of prevention and control of health related hazards.

The Ministry of Environment and Forest (MoEF) deals with environmental impacts or hazards emanating from a new application. It is working with the associated law (Ramani et al., 2011) such as the Environmental Protection Act (EPA) of 1986, Air (Prevention and Control of Pollution) Act 1987, Water (Prevention and Control of Pollution) Act 1974, The Public Liability Insurance Act of 1991, Hazardous Material Rules 2007, The Biomedical Waste (Management and Handling) Rules 1998, and The Municipal Solid Wastes (Management and Handling) Rules, 2000. Ministry of Chemicals and Fertilizers (MCF) via the Department of Pharmaceuticals (DP) finances projects on the toxicological aspects of nanomaterials in National Institute of Pharmaceutical Education and Research (NIPER). It has also the instruction for conducting programs on drug surveillance, community pharmacy and pharmaceutical management. Other civil society organizations such as TERI focuses on understanding the regulatory issues and the challenges posed by nanotechnology in India.

5.1. Environmental, Health and Safety Issues

The development of nanotechnology raises ethical questions about its possible impacts on health and the environment.Impacts of nanomaterials on the environment and human health are undefined. Nanoparticles can enter the blood stream through the lungs and possibly through the skin and seem to enter the brain. Other human health concerns include largely unknown effects of using nanotechnology in pharmaceuticals. These nanoparticles will also enter the food chain, affecting plants and animals. It is also not known if these particles are biodegradable (D'Silva, 2007). Douglas and wildavsky (1980)focusses on the social functions of risk. Social amplification of risk is and important issues in the analysis of risk.

It refers to social consequences arising out of technical and economic risk. It may result in undesirable social consequences such as debt, poverty and destitution.

The Bureau of Indian Standards (BIS) has responsibility for standards for nanotechnology in India, including safety standards (Sen, 2008). It follows all the recommendations set by the international organization of standards (ISO). In 2005 the ISO started a committee, ISO/TC 229, to develop standards, nomenclature, and health and environmental standards for nanotechnology. The major channel between the ISO and the Indian BIS is the MTD 33, a working group set up by the BIS to serve as the liaison to the ISO. The MTD 33 includes professionals from industry, academia, and the government sector (Bureau of Indian Standards, 2010). There are four other organizations involved with developing health and environmental regulations for nanotechnology in India: the Ministry of Environment and Forests (MoEF), the Ministry of Chemical and Fertilizers (MoCF), the Ministry of Health and Family Welfare (MoHFW), and the Ministry of Labour and Employment.

The MoEF regulates hazardous waste and sets regulations to protect land, air, and water quality. It is one of the prime organizations for setting environmental standards for nanotechnology. The MoCF regulates chemicals, which means it is charged with regulating many nanomaterials (Ramani et al., 2011). The MoHFW is charged with a variety of social concerns such as diseases, medicine control and family services such as reproductive health and pediatrics. With regard to nanotechnology, the Drugs and Cosmetics Act of 1940 gives this ministry the power to regulate drugs and cosmetics, which means that any nanoparticles found in these sectors will be regulated by the MoHFW. Finally, the Labour and Employment regulate labour, safety standards, child and women labour policy, and labour laws.

6. Challenges of Nanotechnology Innovation in India

A conceptual framework to measure national capability to respond to nanotechnology development needs to address the key opportunities and challenges created by the nanotechnology in terms of the demands imposed on the science and technology infrastructure and by changing the nature of science and technology. There are several issues emerge in the nanotechnology development in India (TERI, 2010):

- The main challenges for the application of nanotechnology sector are the improvement of efficiency, reliability, safety and lifetime, as well as the reduction of costs.
- One of the biggest challenges has been in terms of the interdisciplinary nature of nanotechnology and the scope of its applications. This has led to significant overlaps in the areas to R&D support identified by different agencies.
- The gap between basic research and application is another challenge in nanotechnology. There is poor lab firm integration, which is compounded by the paucity of skilled manpower that could provide linkages between the technology and commercial domains.
- High nanotechnology costs for acquisitions of intellectual property rights, nanotechnology infrastructure, lack of human and policy capacity, and venture capital mechanisms are nearly non-existent
- Safety, health and environment (SHE) risks to consumers and the public need to be addressed while commercializing nanotechnologies as some of the nano products are perceived to possess such risks in their life cycle and there is no regulatory mechanism existing to evaluate the potential risks of nanomaterials (Purushotham and Madhuri, 2011; Purushotham, 2012).
- There is a need for addressing nanotechnology risks in the societal context.

7. Conclusion

The nanotechnology development at present is in its initial stages in India. The Government of India has been encouraging the growth of the sector by funding projects under various programs of DBT, DST, DSIR, ICMR, MNRE and ICAR. Other stakeholders such as universities, research institutes, and private firms are also emerging as important players in this area.It is an emerging technologyarea currently dominated by public laboratories in India. The steep growth in number of publications and patents from India on nanotechnology shows the magnitude and continued incentive received from the field. A number of partnerships between companies and research institutes and academia to develop and commercialize specific technology have been formed. The situation forms well for the rapid development of new products, new markets and new competencies.

Nanotechnology could be both relevant and appropriate to sustainable development practices in India. In an area such as tuberculosis and rural health, clean water, renewable energy food packaging and agriculture fertilizers. It has the potential to allow a limited response to challenges such as the diagnosis and treatment of infectious disease. There is also a danger in viewing nanotechnology as a solution to developing country challenges. Therefore, it is necessary to develop responsible nanotechnology governance, encourage the development of appropriate products targeted to help meet critical human development needs, and include methods for addressing the safety, appropriateness; accessibility and sustainability of nanotechnology meet the developing countries like India.

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