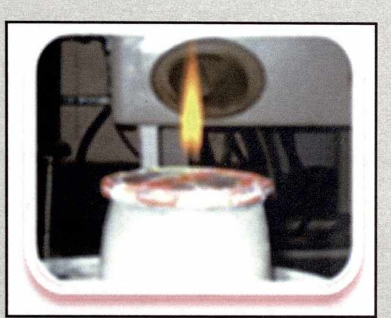
Knowledge Creation and Innovation in Nanotechnology: Contemporary and Emerging Scenario in India

Project Completion Report





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सत्यमेव जयते

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Acronyms and Abbreviations

ACMA	Automotive Component Manufacturers Association
AFM	Atomic Force Microscope
AIMDD	Active Implantable Medical Devices Directive
ARCI	International Advanced Research Centre for Powder Metallurgy and New Materials
ASSOCHAM	Associated Chambers of Commerce and Industry in India
ASTM	American Society for Testing and Materials
BARC	Bhabha Atomic Research Centre
BEL	Bharat Electronics Limited
BHU	Banaras Hindu University
BIG	Biotechnology Ignition Grant
BIS	Bureau of Indian Standards
BRICS	Brazil, Russia, India, China and South Africa
BRNS	Board of Research in Nuclear Sciences
CEN	Centre for Excellence in Nanoelectronics
CII	Confederation of Indian Industry
CKMNT	Centre for Knowledge Management of Nanotechnology
C-MET	Centre for Materials for Electronics Technology
CMOS	Complementary Metal–Oxide–Semiconductor
CNTs	Carbon Nanotubes
COE	Center of Excellence
CSIR	Council of Scientific and Industrial Research
CSIR-CGCRI	Central Glass and Ceramics Research Institute
CSIR-NIIST	National Institute for Interdisciplinary Science and Technology
CSIR-NML	National Metallurgical Laboratory
CSIR-CDRI	Central Drug Research Institute
CSIR-CECRI	Central Electro Chemical Research Institute
CSIR-CEERI	Central Electronics Engineering Research Institute
CSIR-CFRI	Central Fuel Research Institute
CSIR-CFTRI	Central Food Technology Research Institute
CSIR-CGCRI	Central Glass and Ceramic research Institute
CSIR-CLRI	Central Leather Research Institute
CSIR-CMERI	Central Mechanical Engineering Research Institute
CSIR-CSIO	Central Scientific Instrument Organization
CSIR-CSMCRI	Central Salt and Marine Chemicals Research Institute
CSIR-IGIB	Institute of Genomics and Integrative Biology
CSIR-IICB	Indian Institute of Chemical Biology
CSIR-IICT	Indian Institute of Chemical Technology

CSIR-IIP	Indian Institute of Petroleum
CSIR-IITR	Indian Institute of Toxicology Research
CSIR-IMMT	Institute of Minerals and Material Technology
CSIR-IMT	Institute of Microbial Technology
CSIR-NAL	National Aerospace Laboratories
CSIR-NCL	National Chemical Laboratory
CSIR-NEERI	National Environmental Engineering Research Institute
CSIR-NIO	National Institute of Oceanography
CSIR-NISTADS	National Institute of Science Technology and Development Studies
CSIR-NML	National Metallurgical Laboratory
CSIR-NPL	National Physical Laboratory
CSIR-RRL	Regional Research Laboratory
DAE	Department of Atomic Energy
DBT	Department of Biotechnology
DIT	Department of Information Technology
DRDO	Defence Research and Development Organization
DSIR	Department of Scientific and Industrial Research
DST	Department of Science & Technology
ECLA	European Classification System
EHS	Environment Health and Safety
ELSI	Ethical Legal Societal Issues
EPO	European Patent Office
FICCI	Federation of Indian Chambers of Commerce and Industry
IACS	Indian Association of Cultivation of Sciences
IBID	India Business Insight Database
IBSA	India, Brazil, South Africa
ICANN	International Conference on Advanced Nanomaterials and Nanotechnology
ICAR	Indian Council of Agricultural Research
ICMR	Indian Council of Medical Research
ICONSAT	International Conference on Nano Science and Technology
ICPC Nano Net	International Cooperation Partner Countries Nano Network
ICT	Information and Communication Technology
IISc	Indian Institute of Science
IISER	Indian Institute of Science Education and Research
IIT	Indian Institute of Technology
INUP	Indian Nanoelectronics User Program
IPC	International Patent Classification
IPO	Indian Patent Office
ISO	International Organization for Standardization
ISRO	Indian Space Research Organization
IUAC	Inter University Accelerator Centre

IUPAC	International Union of Pure and Applied Chemistry
JNCASR	Jawaharlal Nehru Centre for Advanced Scientific Research
KNNI	Korean National Nanotechnology Initiative
LCA	Life Cycle Analysis
MCIT	Ministry of Communication and Information Technology
MDD	Medical Devices Directive
MEMS	Macro Electro Mechanical Systems
MNRE	Ministry of New and Renewable Energy
MoEF	Ministry of Environment and Forest
MoFPI	Ministry of Food Processing Industry
MoHWF	Ministry of Health and Family Welfare
MoST	Ministry of Science and Technology
MoWR	Ministry of Water Resources
NATAG	Nano Applications and Technology Advisory Group
NATDP	Nano Applications and Technology Development Programme
NEMS	Nano Electro Mechanical System
NILI	Nano-Manufacturing Industry Liaison
NIMITLI	New Millennium Indian Technology Leadership Initiative
NIPER	National Institute of Pharmaceuticals Education and Research
NMC	Nano Mission Council
NNI	National Nanotechnology Initiative
NPMASS	National Programme for Micro And Smart System
NPSM	National Programme for Smart Materials
NRDC	National Research Development Corporation
NSTI	Nano Science and Technology Initiative
NTTC	National Technology Transfer Center
OECD	Organization for Economic Cooperation and Development
PCT	Patent Cooperation Treaty
REACH	Registration, Evaluation, Authorization and Restriction of Chemicals
SCI-E	Science Citation Index-Expanded
SIAM	Society for Indian Automobile Manufacturers
SINP	Saha Institute of Nuclear Physics
SLINTEC	Sri Lanka Institute of Nanotechnology
TERI	The Energy and Resources Institute
TIFAC	Technology Information, Forecasting and Assessment Council
TIFR	Tata Institute of Fundamental Research
USPTO	US Patent and Trademark Office
VAMAS	Versailles Project on Advanced Materials and Standards
VIT	Vellore Institute of Technology
VSSC	Vikram Sarabhai Space Centre
WIPO	World Intellectual Property Organization

Executive Summary

This study was undertaken with the intention to explore and assess the developments surrounding nanotechnology in India. It investigates capacity creation, output and outcome of India's involvement in this field by examining policies, strategies, programs, funding, stakeholder's involvement, governance mechanism, etc. The study also examines policies and strategies of other countries and discerns 'positive outcomes' that can be adopted. The primary objective of the examination is to identify initiatives that have led to 'positive outcomes' so that those programs can be strengthened further, identify opportunities and gaps that if not addressed may impede the development and suggest plausible strategies for developing the nanotechnology research and innovation ecosystem and commercialization.

Nanotechnology: the field, its complexity and challenges

Nanotechnology involves developing the ability to control the shape, size, and chemical composition of structures in the 1-100 nanometers scale (10^{-9} meter; one ten thousandth of a millimeter). For comparison, a human hair is approximately 80,000-100,000 nanometers wide whereas a strand of human DNA is 2.5 nanometers in diameter. Particles and structures of this size differ from their counterparts in the microscopic world in two fundamental aspects: the relative surface area of such structures increases enormously, and quantum effects occur. This results in significant modification of physical, chemical and optical properties leading sometimes to novel effects that can radically change process/product configuration. Development of sophisticated instruments has made it possible to manipulate and create novel materials and structures at the nano scale.

The pervasive potentiality of nanotechnology of being a generic, horizontal, enabling and/or disruptive technology with its potential to revolutionize a wide range of technological sectors, fields, application and process has generated a great deal of excitement worldwide. Nanotechnology is already making an impact in manufacturing, energy solutions, medicine, automotive, ICT, etc by enhancing the functionality/development of novel processes and products therein. For instance, in ICT applications the advantages are in enhanced power to compute and lower power consumption, low cost microprocessors with huge memory capacity and organic large area displays with much higher resolution. Nanotechnology is particularly appealing to developing economies such as India as along with the promise of improving the functionality of existing products/processes or creating new products, it can provide novel interventions in areas that are of pressing concerns i.e.

environment, water purification, agriculture, energy. Thus if properly addressed, nanotechnology can provide a 'window of opportunity' for developing countries to leapfrog and 'catch up' with the developed North.

Developing competency in this field is an immense challenge as it is a science intensive technological field which is highly interdisciplinary, capital intensive, requires sophisticated instruments, skilled interdisciplinary manpower, etc. The field is evolving and thus there is a large degree of uncertainty which creates ambiguity ranging from properly defining the field itself, developing regulatory framework that can address among others the risk aspects, and patent examination criteria's, etc. Creating competence requires factoring all these issues in the policy and creating institutional structures for implementation, regulation and standardization.

Governance of nanotechnology calls for strong linkages of the policy makers/funding agencies with the different stakeholders ranging from academia, industry to the public at large. It involves planning, funding prioritizing and facilitating the creation of knowledge base, development of research and innovation ecosystems, creation of supporting institutions and framework for technology regulation, skill development, IPR, risk and standards, etc. It also involves creating institutions for developing interfaces between upstream and downstream activities. One of the key issues in nanotechnology governance is regulation and risk mitigation which can lead to responsible technological development (address economic and social welfare without any adverse implications).

Uncertainty about the effects/potential impacts of this technology makes creating a regulatory framework, a challenging exercise. Nanotechnology governance is not a locale specific activity. It involves processes and involvement of multiple actors at national level which directly and indirectly shapes and gets shaped by nanotechnology development at international level. Therefore the issues of standardization, regulation, patentability and commercialization is not only country specific but are influenced by wider global factors. This calls for developing governance framework that is dynamic and can address international regulatory guidelines, at least guidelines applicable in major European and USA as these are major markets for high technology products.

Learning from different countries

The study has examined nanotechnology initiatives of different countries particularly USA, China, South Korea and to some extent activities in some Asian countries. Distinct models can be discerned from different countries approach to nanotechnology development. However, there are many commonalities in policies and strategies adopted by different countries. Possibly this commonality is due to the strong influence of US NNI: National Nanotechnology Initiative launched in 2001. One of its major influences is their 'mission oriented'/dedicated funding support which has been adopted by majority of countries in varying degrees. Countries have also created roadmaps for short term to long-term approach following NNI roadmap to a large extent.

Distinct features however, emerge in countries roadmap articulation/policy formulation and implementation. Countries with advanced scientific capacity and highly efficient innovation ecosystem are more ambitious; have an expansive approach and have programs to enhance capacity for nanotechnology intervention in different sectors. Among their central goal is to make their industry competitive particularly manufacturing competitiveness in different sectors through nanotechnology based intervention. Institutional mechanisms and support structures have been created to develop the research innovation ecosystem. Along with strengthening the existing institutional structures, new institutional structures are being created to accommodate nanotechnology. This model mainly observed in advanced OECD countries is also being followed to some extent in emerging countries such as BRICS countries. On the other hand, countries such as Sri Lanka, ASEAN countries with more constrained resources/scientific diversity are focusing on end user applications (directing focus on a specific problem in which nanotechnology intervention can make significant positive changes). For example, Sri Lanka directed focus on applying nanoparticles to improve adhesion of tyres to the road, reducing the stopping distance in wet conditions. It is important to learn from these countries also as directed and targeted approach can play a key role in solving pressing problems.

India's nanotechnology initiatives

In India nanotechnology as a distinct area of government research support started in 2001 with the launch of NSTI (Nanoscience and Technology Initiative) in the tenth plan period (2001-2006) with an allocation of rupees 60 crores (approx. USD 12 million). This programme was articulated and implemented by the Department of Science and Technology (DST), Government of India. In international comparison this amount was insignificant but on the other hand it signaled Indian government commitment to this new emerging field. This programme helped in creating basic infrastructure in the country to undertake nanotechnology research. Department of Information Technology (DIT) also started dedicated programs in nanoelectronics during this plan period.

In the eleventh plan period (2007-2012) more ambitious programmes and targets have been set. Among the major step taken was the launching of 'Nano Mission', follow up of the NSTI programme. It has been allocated Rs 1000 crores (250 million USD), accounting for 36% of the budget allotment in mission mode programs in the eleventh plan period. This programme has strengthened the activities undertaken in NSTI and also new initiatives have been started to develop the nanotechnology research and innovation ecosystem. Among the new initiatives include benchmarking and supporting degree programs in nanotechnology, creating centers of excellence, facilities for access to sophisticated instruments, international collaborative programs, and fostering public-private partnerships. DIT has also undertaken more large-scale programs to develop the nanoelectronics community — centers of excellence in nanoelectronics, INUP programme which provides access to sophisticated instruments, funding and peer support.

The Indian nanotechnology initiative has now evolved as a multi-agency effort with the involvement of other key scientific agencies and stakeholders namely Department of Biotechnology (DBT), Council of Scientific and Industrial Research (CSIR), Ministry of New and Renewable Energy, Ministry of Health and Family Welfare, Indian Council of Agricultural Research, Indian Space Research Organization, Department of Atomic Energy, and Defence Research and Development Organization. Their involvement has helped to strengthen nanotechnology intervention in different sectors, for example DBT (nano-medicine), CSIR (energy, metrology, nano-medicine/pharmaceuticals), ARCI (water, textile, smart materials). Universities have started degree programs and research from their internal funds and some have received extramural research grants. Centers of excellences and nanotechnology centers have been created in some major universities from funding by Nano Mission, DIT and others.

A few companies are also seriously looking at this area. Some of the big companies like Tata, Reliance, and Panacea Biotech have opened dedicated nanotechnology R&D center. Some foreign R&D centers namely General Electric, Intel among others have started user driven research in this field. Industrial associations CII, FICCI, ASSOCHEM are also trying to develop and push government bodies to focus on strategies for industrial involvement in nanotechnology research, regulation and commercialization. Involvement of sector specific associations such as automotive association SIAM is also beginning.

Nanotechnology capacity creation in India

The involvement of different stakeholders has led to the creation of capacity particularly research capacity. Centers of excellence have been created in different parts of the country in institutions actively involved in nanotechnology research with the intention of acting as geographical hubs for catalyzing research and innovation. Individual and capacity building projects (procurement of advanced instruments, etc) has helped the research community to develop expertise. International collaborative programs have been initiated with different countries with well directed focus — access to complementary skills, advanced instruments, peer groups, thematic/sectoral programs, etc. Nanotechnology requires interdisciplinary manpower drawing from different fields of science and engineering. Different universities have started dedicated degree courses at graduate level i.e. B.Tech (mainly private university), and post-graduate level (M.Sc/M.Tech). Nanotechnology is now included in the curriculum of graduate/post-graduate level degree programs of science/engineering in many universities or is taken up in post-graduate dissertations. PhD and post-doctoral research are now visible in many institutions. Some efforts are being made to develop benchmarks for course content and uniformity. Model M.Tech course curriculum has been developed by JNCASR. Nano Mission has also evaluated and benchmarked universities imparting nanotechnology courses at post-graduate level. Students and young researchers are also getting access to advanced instruments such as nanofabrication facility available through INUP programme, which is helping in skill development. Some national conferences ICONSAT, Bangalore Nano are having dedicated sessions for students and young researchers to showcase their work and interact with peers.

One can observe now, after a decade of the start of nanotechnology initiative by the government of India, research ecosystem developing in this field with dedicated research groups in universities/research institutes. The capacity is getting more dispersed (nanotechnology research activity is observed in academic centers across the country). Also, it is getting more directional i.e. groups are emerging in key thematic areas.

Outcome of India's nanotechnology initiative

Promising leads are emerging from research with novel applications already visible. One of the key features that draw attention is research groups working in developing nano-based applications in areas of pressing concerns namely effective drug delivery, safe drinking water, and energy. Domain specific capabilities are being created; this is particularly visible in nanoelectronics primarily due to the DIT involvement. Similar developments can be observed in the area of water, textiles, energy and health.

The most tangible outcome of India's nanotechnology development is the impressive growth in research papers. India is now the 6th most active country publishing in this field based on SCI-expanded database. Significant increase is observed on analyzing the trends over the period (from the start of nanotechnology initiative in the country) in the number of institutes involved in nanotechnology research, in the number of journals used for publishing, more interdisciplinary research (reflection through journals), and activity within different subfields of nanotechnology.

Among the key findings is research collaboration among institutes reflected in papers which is increasing and is instrumental in increasing output, publishing in high impact factor journals and in attracting citations. India is building up on its strength in material science research, applied physics research and physical chemistry while addressing nanotechnology research.

Patenting is in an early stage but show promising signs i.e. they address niche areas of global relevance and in addressing pressing concerns such as in medicine (bio-sensors and drug delivery patents). The areas where India is involved in patent filing and grant activity are 'Nanostructure based therapeutic compounds', 'Chemical process based manufacture of nanostructure', and 'Chemical compound to treat disease'. Most of the patents from India are having biological focus; for example biodegradable polyesters in pharmaceutical compositions, process of immobilizing enzymes, liposomal formulations for oral drug delivery, nutritional supplements to prevent various diseases, bio-sensors. Some other areas where patents are visible include rechargeable batteries, semiconductors, and magnetic nanomaterials.

Indian patenting activity in the US patent office, PCT, European patent office shows it is an insignificant player. Intensive patenting activity is observed in this field in these patenting offices. Patents are undertaken in different stages of the innovation process with dominant activity in nanomaterials (primarily carbon nanotubes), and application of nanostructures. Patents in this field are key instrument in translational/commercialization that has motivated countries active in this field to undertake patenting aggressively. India's low levels of patenting in this field in spite of high levels of research activity are thus a cause for concern.

From lab to commercialization

It is too early to say whether India's significant research activity will lead to economic and social outcomes. A few applications are now visible that are showing promising social and economic outcomes. Some of them have emerged from linkages between academia and industry. In spite of low levels of patenting activity, some patents show promising pathways. Thematic groups are visible in some key areas of pressing concerns — water, medicine and energy. Some support structures are emerging to strengthen the sectoral focus and translational research efforts. For example, Nano Mission is now concentrating on establishing thematic units of excellence i.e. directing focus on creating units that focus on nanotechnology as an enabler in key sectors. Nano Applications and Technology Advisory Group constituted under Nano Mission with the objective to encourage implementation of application-driven projects in the area of nanoscience and technology is in this direction. Nano-biotechnology is being supported under DBT's lab to market initiatives under its BIG (Biotechnology Ignition Grant) scheme. CSIR's NIMITLI programme has initiated academia-industry partnership projects in nanotechnology. ISRO, DRDO, etc. are also inviting industry partnership in their nanotechnology research. Tata Chemicals, Reliance, Panacea Biotech are creating their own R&D centers dedicated to nanotechnology research. Some novel applications/products have emerged from these centers.

In spite of some tangible outcomes, there is a long way for 'promising research' leading to applications. Only, a few organisations have been able to translate some of their research to applications. Even many of the applications are in pilot stage and have to scale up before entering the market. Major policy directive with well defined action plan is required for creating the environment (support structures, and functional linkages) that develops/strengthens synergy between academia and industry.

Nanotechnology Regulation

Regulation including risk regulation requires very strong push as this is still not properly addressed. Regulation requires accommodating concerns of different sectors where nanotechnology intervention are being undertaken and action plan for addressing them. Moreover, international regulations are evolving such as nanomaterials being defined under chemicals and guided by REACH provision in the European framework. Thus, regulatory framework has to be dynamic and evolve to meet international regulations particularly those visible in major developed countries.

There is no explicit budget allotted for EHS/ELSI and issues covering them are still not in the mainstream discussion and policy articulation. Lack of attention to these issues may adversely impede the development process. Lately some initiatives have been taken for addressing risk issues by Nano Mission and key scientific agencies. NIPER is developing regulatory approval guidelines for nanotechnology based drugs and standards for toxicological tests in nano-based drug delivery systems. In 2010, DST appointed a task force which has been asked to advice Nano Mission Council to develop a regulatory body for nanotechnology in India. Firms involved in nanotechnology based product development primarily products addressing water, textile, drug delivery have undertaken Life Cycle Analysis (LCA) partnering with research institutes/universities. Standardization remains an area of concern. India, has only taken initial first steps in addressing standardization issue.

Final Remarks and Strategic Priorities

Extensive investments have been made by different countries in this field with the hope that this will pay-off in terms of economic and social benefits. The 'return to investment' in terms of economic and/or social goal is more pressing for emerging/developing countries as they perceive this technology can help them in the 'catch-up' with the advanced North. Along with this, the potentiality of this technology to address their developmental goals has motivated them to allocate a high proportion of their R&D budget towards this area. This prioritization creates demands for visible outcomes which apply to a large extent for India. The study has examined the efforts undertaken by India to develop capacity for nanotechnology research and innovation in the country and have identified visible outcomes. This assessment shows what has been achieved and the major gaps that need to be addressed. The study argues that properly addressing the gaps can strengthen the present efforts and can lead to responsible nanotechnology development.

Examining dedicated government driven promotion of nanotechnology over a period of more than ten years from its initiation shows some very positive actions have been undertaken. The tangible outcomes particularly the infrastructure created for undertaking nanotechnology research in different domains has been possible because of this government driven intervention. Centers of Excellence have been created in different parts of the country and focused thematic units are being created in the field of water purification, photovoltaic and sensors, medical biotechnology, and automotive application. These centers are playing an important role in developing the research community. Distinct research groups are now emerging in the country. They are now becoming more directed and focusing on sectoral issues/problematic.

There are two kinds of challenges that have to be taken into account and need to be addressed for responsible nanotechnology development in a country. First set of challenges are in the global context of nanotechnology development such as the level of knowledge development globally, regulatory framework in different countries including risk guidelines, standards development, patenting intensity and nature of patenting, patentability examination guidelines, etc. Second set of challenges are country specific and relates to its research and innovation ecosystem in general and aspects covering nanotechnology in particular such as capital intensiveness, sophisticated instruments, interdisciplinary nature of this field that requires specialized human resource generation, academia-industry linkages, translational research capacity, etc.

The study recommends a set of actions that should be undertaken for responsible nanotechnology development in the country. These recommendations are based on this exploratory study i.e.

investigating Indian nanotechnology activity over a period of time and also examining development strategies and outcomes of some advanced and emerging economies in nanotechnology. They are articulated as strategic priorities. The study posits that by addressing them the country's nanotechnology programme will be strengthened i.e. lead to the enhancement of the nanotechnology research and innovation capacity and create suitable mechanisms for research translation; developing novel products/processes that can meet economic and/or social goals, enhance industrial competitiveness.

Strategic Priority 1

Nanotechnology in India has evolved as a multi-agency program with involvement of different government agencies providing support for capacity building and sectoral intervention. ***The study recommends creation of an empowered structure that can coordinate investment in research and development (R&D) activities in nanoscience and technology.*** This will create horizontal linkages among different agencies which among others help in coordinated approach to key elements for nanotechnology development such as human resource development, regulation, capacity building, etc.

Strategic Priority 2

Developing skilled human resource in this area is challenging as it calls for interdisciplinary competency along with grounding in natural science/engineering. ***The study recommends (a) Creation of interdisciplinary courses and separate program in nanotechnology at post-graduate level that meets the requirement of industry at large (b) Creation of advanced certification/diploma in nanotechnology for imparting students various skills (handling advanced instruments, patenting aspects, etc) and industrial exposure.***

Strategic Priority 3

The study shows that well defined mission program and involvement of various scientific agencies has led to the creation of 'research ecosystem'. ***The study recommends that in the next phase it is important to develop a Roadmap/Framework that helps progression from 'research ecosystem' towards an 'innovation ecosystem' and commercialization.***

The roadmap should have a balanced approach: along with strengthening discipline based objectives it should also give emphasis to social needs. It needs to create opportunities for different stakeholders and should have short, medium and long term perspective. For example, short term perspective need to pay attention for exploiting existing knowledge. More focus would be towards development and creating interface mechanisms for scaling up the technology, industry partnership, etc. Medium and particularly long terms perspective would incorporate strategies of short term but also need to place sufficient resources for creation of knowledge, develop governance framework, regulation, etc.

The Roadmap should also give due emphasis for strengthening collaboration/strategic partnerships between academia and industry. Institutional support mechanisms such as Centers of Excellence and Nanotechnology Centers that have been created can act as bridges for developing linkages, creating partnerships in the whole value chain of technology development i.e. from research to innovation and product design. The centers needs to be augmented with different support systems therein such as technology transfer office, patent examination and filing facility, incubation and proof of concept funding, state of art search for assessing current developments, etc. These centers should help in bridging fundamental science and real world applications in different sectors.

Nanotechnology has multiple applications in myriads of sectors. Each sector has its own distinctiveness, inherent dynamism, concerns which needs to be addressed for responsible intervention of nanotechnologies in that sector. Sectoral concerns should be taken into account in the Roadmap.

Strategic Priority 4

Nanotechnology development is to a very large extent contingent on access to sophisticated instruments. ***The study recommends dedicated instrumentation program for developing sophisticated instruments.*** The program should be backed by specific policy articulation with long term dedicated funding and with the involvement of academia and industry. This includes developing international collaborations for joint instrumentation development.

For increasing access to sophisticated instruments; existing programs like INUP should be strengthened further by creating more nodal points; access to international facilities such as European Synchrotron Radiation Facility (ESRF), beam lines, etc.

Strategic Priority 5

The questions of nanotechnology definition and classification, examination, international rules, etc are key concerns in patenting and standardisation. Institutions engaged in nanotechnology research should have more horizontal linkages with patent office, and standard development institutions. ***The study recommends development of a centre of excellence to examine patenting (patent guidelines in this area, facilitating the patenting process, etc) and other IPR issues, develop linkages between academia and patent office, create joint mechanisms for developing sector specific standards, etc.***

Strategic Priority 6

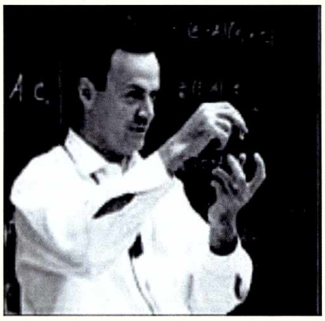
Governance mechanism including regulation and risk mitigation requires urgent attention. ***The study recommends dedicated funding support for EHS/ELSI including creation of a coordinating centre for regulation and risk research.*** The centre needs to address the aforesaid issues in the whole value chain of a product/process development. Regulatory and risk aspects should focus on each sector and take in account the sector specific peculiarities and challenges.

Strategic Priority 7

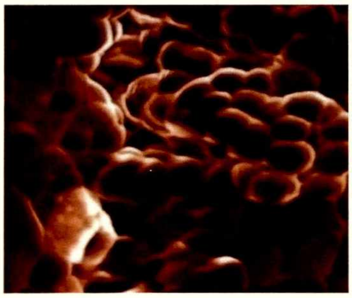
Assessment exercise are very important to gauge the status of the various programs i.e. to what extent they are addressing the objectives; whether the programmes properly address the contemporary and emerging trends, new directions to strengthen the programs, etc. ***The study recommends continuous monitoring and periodic detailed assessment of research and innovation capacity, outcomes and outputs, identify shortcomings and assess new opportunities.***

1. Nanotechnology: A 'Window of Opportunity' for Developing Countries

1.1 Introduction



"I would like to describe a field (nanotechnology), in which little has been done, but in which an enormous amount can be done in principle"
Richard P. Feynman February, 1960

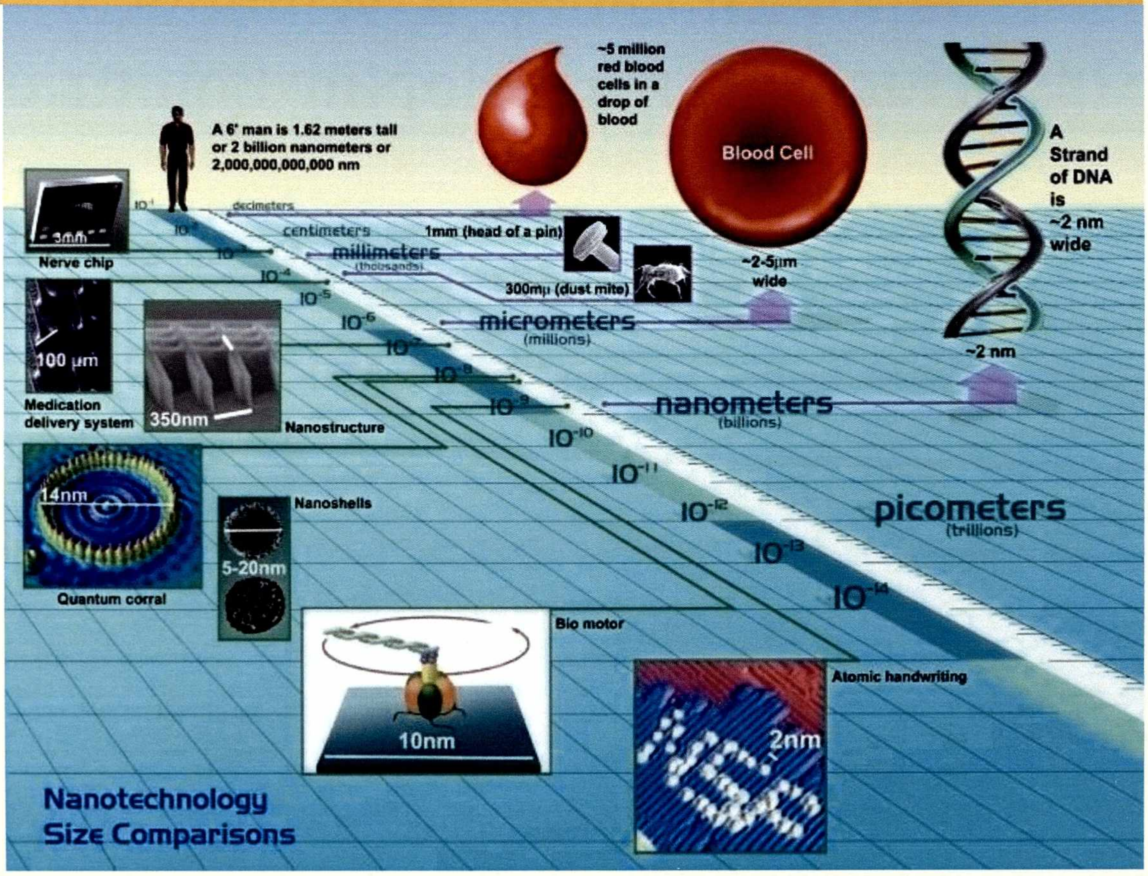


To understand the very large we must understand the very small' — Democritus (470-380 BC)'

Nanotechnology is not a discreet technology or an industry sector. It simply refers to a range of technologies that operates at the nano-scale (roughly 1-100 nanometers, one nanometer is 10^{-9} meter). Although 'size' is a convenient way of defining this area; in practice nanotechnology has more to do with the investigation of novel properties that manifests themselves at the size scale, and the ability to manipulate and artificially construct structures at that scale.

Nanotechnology basically includes use of techniques to understand phenomena and engineer structures in the physical range of 1-100 nanometers (nm) [from the size of an atom to the wave length of light]; as well as incorporation of these structures into applications. Figure 1.1 shows the size and scale in the nanotechnology context.

Figure 1.1: **Size and scale of nanotechnology**



Source: *http://nanohub.org/resources/11965/watch?resid=12402#time-3:03*

Although 'size' is a convenient way of defining this area; in practice nanotechnology has more to do with the investigation of novel properties that manifests themselves at nano scale, and ability to manipulate and artificially construct structures at that scale. To overcome ambiguity in patentability, standard creation, and regulatory response, and distinguishing products/processes as nanotechnology based, more informed definitions have been created by the European Patent Office (EPO), United States Patent and Trademark Office (USPTO), US National Nanotechnology Initiative, International Standard Organization (ISO), Organization for Economic Cooperation and Development (OECD), among others. Each of these definitions is context specific with the primary objective to provide clarity to their involvement in this field. While all these definitions differ in the precise wording, primarily they stress its character of being a bridging technology (Sheu *et al.*, 2006). Three characteristics of nanotechnology can be delineated from different definitions. Firstly, nanotechnology focuses on materials or processes for which minimum one component is in the nanometer-scale. Secondly, control, handling and manipulating at very small scale is emphasized.

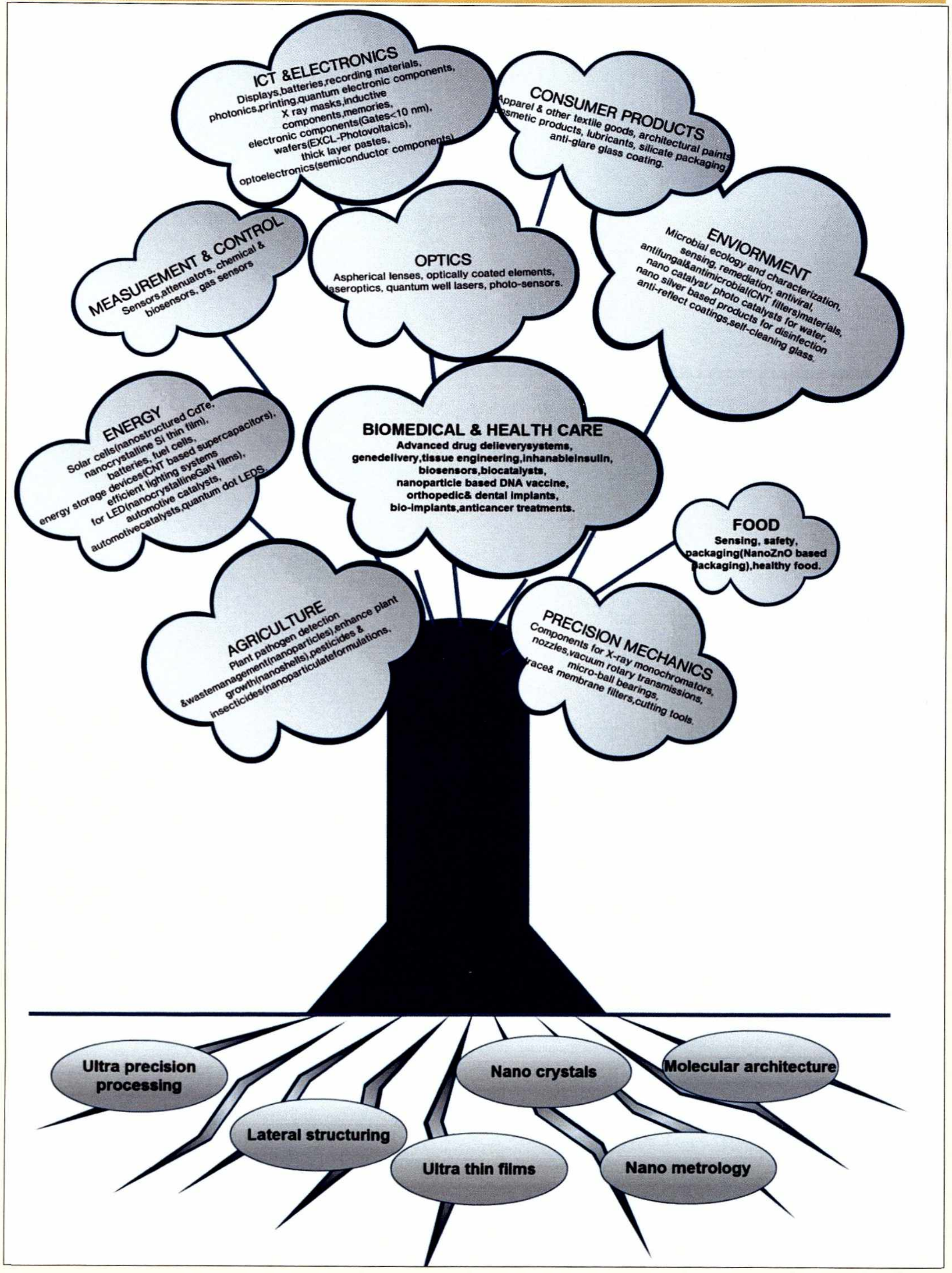
This excludes all "accidental" nanotechnology which can be also described as "natural" nanotechnology and occurs without any engineering or functionalizing process step. Thirdly, commercialization aspect is highlighted in all definitions. Nanotechnology enables new industrial applications as well as technological innovations. Convergent character of nanotechnology underlay's all the definitions.

'It is amazing what one can do just by putting atoms where you want them'
Richard Smalley, Nobel Laureate and Co -discoverer of the Buckyball

At nano-scale, some materials gain radically new characteristics and functionalities that can be used for innovative applications in myriad sectors (Bhattacharya and Bhati, 2011). For instance, gold, which in bulk form is inert, turns out to be highly effective catalyst when reduced to nanometer range. Infusing carbon atoms into nanotube structures makes the structures stronger than steel, conducts electricity better than copper and becomes virtually impervious to heat.

The new scale facilitates manipulation on the cellular level, thus enabling new discoveries in pharmaceuticals, bio-defense and health care. In cancer research, quantum dots are being used to study tumors and locate proteins. These are metallic particles that emit bright light in a color range that varies with their size. Whereas chemotherapy kills cells indiscriminately, nanoparticles once introduced into a tumor and subjected to a specific wavelength of light, target and destroy only the cancer cells. This process requires fewer drugs and is safer for patient. Nanotechnology interventions can be observed similarly in different areas that can lead to solutions of pressing problems/complexity. For example, in water treatment, re-use/engineered nanoparticles can provide a number of opportunities: high absorption that can help remove arsenic and other heavy metals, anti-microbial properties, fouling-resistant, filtration membranes, florescence that can detect pathogens and other primary pollutants. Products are already in the market and more multi-functional water treatment/re-use products are being developed.
This pervasive potentiality of nanotechnology of being a generic, horizontal, enabling and/or disruptive technology makes it most attractive. Nanotechnology is already addressing key economic sectors and can provide solutions to some of the world's most critical development problems. Figure 1.2 highlights areas where nanotechnology is already providing novel solutions.

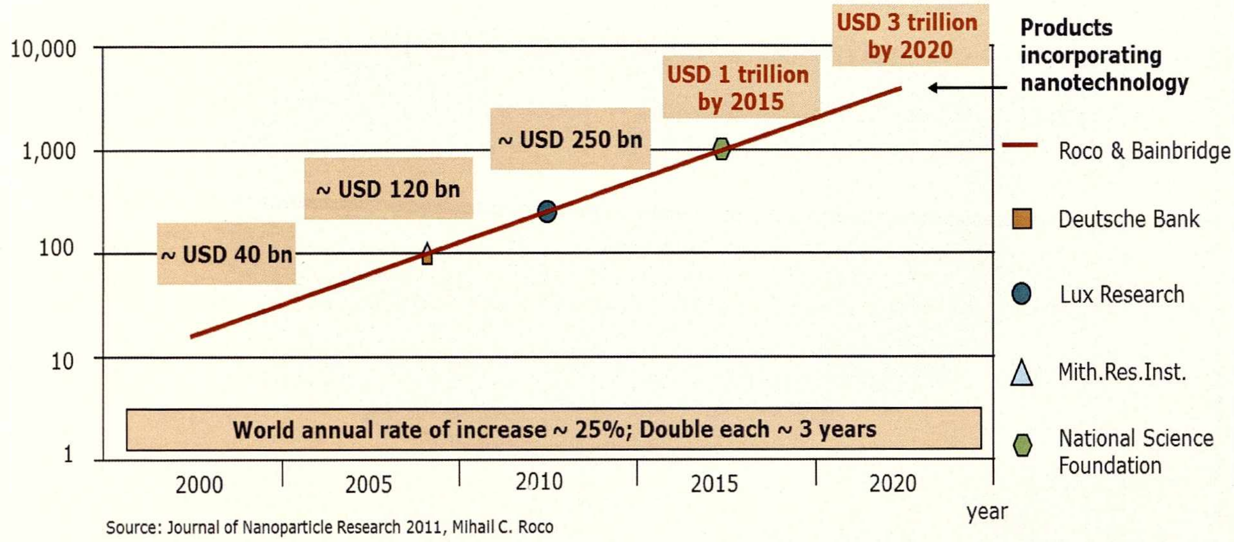
Figure 1.2: **Various nanotechnology enabled application**[1]



[1] This figure was influenced by Martin Meyer's Nano Bonsai Tree, Meyer (2005). This has been expanded based on the applications visible in the contemporary period. Also applications that address environmental and developmental areas were captured.

Different studies forecast that the global market and impact of nanotechnology in key functional components by the year 2015 to be in the range of $1 to $2.6 trillion (see Figure 1.3 below), with requirement of two million workers, and about three times many jobs in supporting activities.

Figure 1.3: **World market incorporating nanotechnology (Billion USD)**



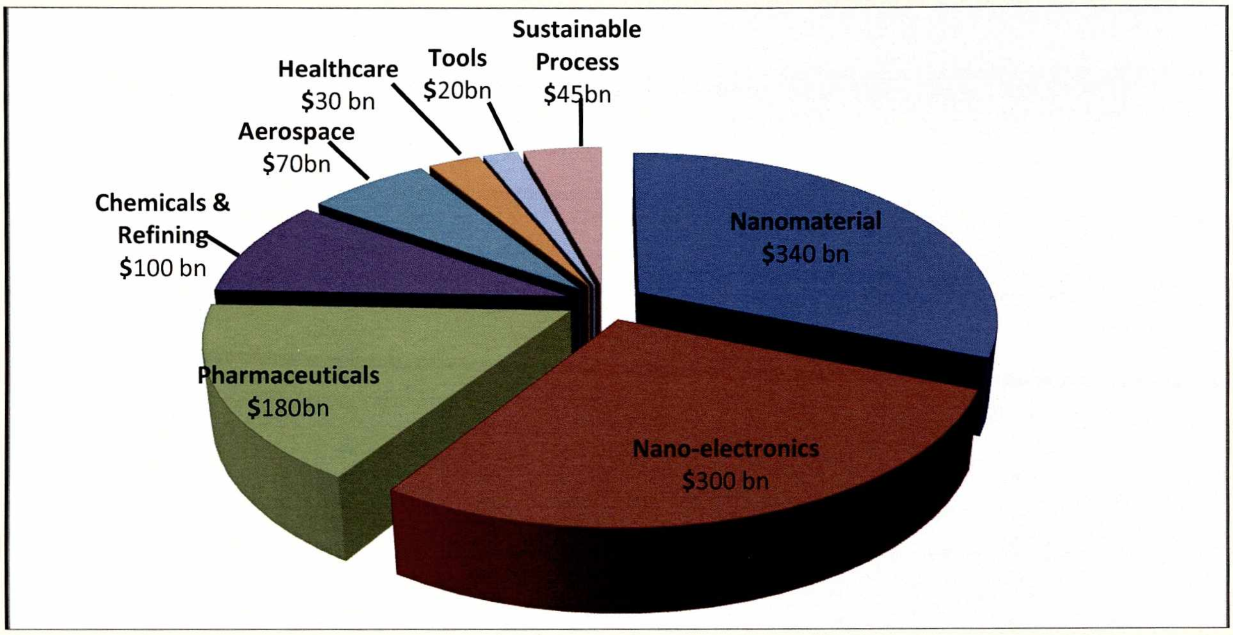
Source: Journal of Nanoparticle Research 2011, Mihail C. Roco

The country that attains 'first mover advantage' in this technology can derive huge economic benefits. Capability in this technology can create monopoly for its firms in strategic/high value areas.

These forecasts suffer from difficulties in defining the value-addition of nanotechnology to existing manufacturing processes as well as its role in generating new products. In spite of skepticism of these estimations, products incorporating nanotechnology are entering the marketplace. These products are estimated to have produced $147 billion in revenues in 2007 (including $59 billion in the United States, $47 billion in Europe, $31 billion in Asia/Pacific, and $9 billion in other nations).

Figure 1.4 shows the market size estimated for different domains within nanotechnology.

Figure 1.4: **Estimated market size* in various sub-domains of nanotechnology**



**In Billion USD*

Source: National Science Foundation (Future Estimation)

Nanotechnology is making inroads in key economic sectors. Nanomaterials cover a wide range of materials which have at least one dimension under nano-scale ('carbon nanotubes', 'dendrimers', etc.).

The large market for nano-materials augers well for countries moving in this high technology area as it is relatively easier to create various types of nanomaterials than in creating nano-enabled products such as nanodevices. Various types of nanomaterials (for example 'carbon nanotubes', 'dendrimers') can provide flexibility of applications i.e. can be used in a variety of applications across different economic sectors. A characteristics that makes nanotechnology appealing is that not only it can provide solutions in high technology but also in areas that are of pressing concerns in developing and impoverished economies i.e. environment, water purification, agriculture, energy and in a host of other products and services (Bhattacharya *et al.*, 2011) (see also Figure 1.2).

Nanotechnology has been seen as both relevant and appropriate to sustainable development practices in developing countries. In areas such as water, agriculture, health, nanotechnology has the potential to empower a local response to development challenges.

Nanotechnology based products in different economic sectors are already in the market. These demonstrated applications are changing the perception of skepticism towards a realization that if properly addressed nanotechnology can provide a 'window of opportunity' for countries to catch up. This has motivated developing countries to channelize their scarce resources for increasing their capacity and capability in nanotechnology. Developing countries also perceive that this technology can help them to 'leapfrog' the technology development lifecycle and compete globally through value enhanced products. This has stimulated OECD countries as well as emerging economies to channelize huge resources for developing core capabilities in this technology.

1.2 Objectives and Justification of the Study

In the last decade or so nanotechnology became one of the high priority areas of funding in advanced as well as emerging economies primarily due to the 'promise' this technology demonstrated of providing solutions in high technologies and also possibility of new pathways for mitigating pressing developmental issues. India like other emerging economies is looking upon this technology as a 'window of opportunity' that would allow them to leapfrog the 'catch up' process. This has led to various initiatives taken by Indian Government to create capacity with directed goals. It is important to make an assessment at this stage, a decade after the nanotechnology programmes have been initiated. Also it is envisaged that this introspection can provide directions for developing nanotechnology roadmaps/policies that can lead to successful economic and/or social outcomes. This study was undertaken with this intention i.e. to explore and assess the developments surrounding nanotechnology in India. It investigates capacity creation, output and outcome of India's involvement in this field by examining policies, strategies, programs, funding, stakeholder's involvement, governance mechanism, etc. The study also examines policies and strategies of other countries and discerns 'positive outcomes' that can be adopted. The primary objective of the examination is to identify initiatives that have led to 'positive outcomes' so that those programs can be strengthened further, identify opportunities and gaps that if not addressed may impede the development and suggest plausible strategies for developing the nanotechnology research and innovation ecosystem and commercialization.

The study addresses the objectives by attempting to answer a set of key questions namely: What are the enabling factors/incentives for nanotechnology R&D in India?; What are the structural characteristic of scientific and applied knowledge and its outcome?; What is the nature of linkages existing among different actors?; What can be the learning experiences from other countries for India in terms of policy formulation, strategy and governance that can stimulate research and innovation in nanotechnology?

1.3 Methodology

The present study intends to capture knowledge creation and innovation in nanotechnology in India; to assess the development over the period of time and to provide inputs for a future roadmap. To have a deeper understanding of the nanotechnology development in the field, global development was also studied. An extensive secondary analysis complemented by limited primary survey of experts and other key stakeholders were undertaken to address the objectives of the study. The underlying intention was to base our conclusions/recommendation through validated evidence based data. Secondary analysis included both qualitative and quantitative approach.

Qualitative analysis was undertaken to map policies, strategies and governance of nanotechnology in major advanced and emerging economies. This helped to understand the various discussions on nanotechnology about the objectives of government policies, the specific actors involved, or the organizational structure of distribution of research funds. Analysis of scholarly articles was complemented by policy documents to understand the nuances of opportunities and challenges posed by nanotechnology development in India and different countries. Besides social science articles and policy documents, reports of various kinds, opinion pieces, websites and newspaper articles were also consulted. Interviews were conducted with scientists, practitioners, policymakers, and industry actors to get a realistic picture of nanotechnology development in India. This helped to capture the opinions amongst heterogeneous actors involved in nanotechnology development in India. Close reading the sources allowed for mapping the various discussions in which challenges that nanotechnology developments may give rise to and are framed by particular actors. It helped in providing a better view on what issues emerge and how they are dealt with than by exclusively relying on scholarly articles.

Quantitative analysis was primarily based on bibliometric indicators constructed from research papers and patents. Nanotechnology evolution is contingent on strong interaction with scientific research. Analysis of research papers thus helps in understanding the knowledge development in this field. Not all products are patented and not all patents yield products. However, in a knowledge intensive area such as nanotechnology, patents are one of the most useful strategies for firms to appropriate value and thus, there is strong tendency to protect their inventions through patents. Patenting activity in nanotechnology is thus able to capture i.e. provides the best estimation of, the inventive ability of a firm or a country and possible indication of creating future novel products. In addition, involvement of various actors and linkages among them can be revealed through the bibliometric indicators. Bibliometric indicators were complemented by indicators of innovation namely standards, and product/process development. Standard activity and international adoption of a country's standard provide an indication more so in a high technology area like nanotechnology of future technology leverage. Standards development also shows the direction of regulatory activity. Products/processes developed provide final indication of a country (ies)/firm(s) ability to assert in a particular technology. For a technology which is at an early stage of development like nanotechnology, only a few products would be in the market. However, they signal early mover advantage for firms/countries.

Publication data was retrieved from the Science Citation Index Expanded (SCI-E), accessed via Web of Science. SCI-E is very efficient in covering global mainstream research areas. The SCI-E covers data from over 8,000 leading scientific and technical journals across 174 disciplines and covers over 100,000 conference proceedings in different subject areas. One of the key issues in bibliometrics is proper harvesting of records. Nanotechnology is a complex field and simple search quarry may not retrieve all the relevant publications. On the other hand, broad search strategy may lead to 'noises'. We applied Kostoff *et al.* (2006) search strategy in this study to overcome this problem. This search string is based on 300+ quarry terms (Annexure I a). The paper by Huang, *et al.* (2011) reviewed the various search strategies for extraction of nanotechnology papers. Search strategy by Kostoff *et al.* (2006), or Porter and Youtie (2008) have been applied by most of the authors for harvesting nanotechnology research publications. On a pilot scale, we did not find substantial difference of records extracted on using either of the search strategies. Content analysis was undertaken based on keywords attached to each article. Along with frequency analysis, co-occurrence analysis of keywords (co-word analysis) was undertaken. This analysis was undertaken using Bibexel, and CiteSpace. Pajek was used for visulization. Mogoutov and Kahane (2007) have defined a search strategy, which extracts nanotechnology records in different fields (Annexure I b). Huang *et al.* (2011) review has shown this is a very relevant strategy. This search strategy identifies (a) overall records in nanotechnology (small variations were found) with what Kostoff *et al.* (2006) search string gives, (b) identifies nanotechnology research activities in eight areas. This search strategy was applied to delineate nanotechnology activity in different disciplinary streams.

Patent statistics was captured from US, European and Indian patent office. Application filed was also captured from Patent Cooperation Treaty (PCT). PCT data was captured from the WIPO website (http://patentscope.wipo.int). US Patent data was captured from the website (http://patft.uspto.gov/) of US Patent and Trademark Office (USPTO). Nanotechnology is classified separately by the USPTO under class 977 which was created by the USPTO to serve as cross-reference to help examiners, among others, search prior art. This classification was used to extract nanotechnology patents from the USPTO. In Class 977[2], the USPTO provides for disclosure related to 'nanostructures[3] and chemical compositions of nanostructures', 'device that include atleast one nanostructure', 'mathematical algorithms', 'methods or apparatus for making, detecting, analyzing, or treating nanostructure', and 'specified particular uses of nanostructure'.

Thomson Innovation database was used to extract patents from the European Patent Office (EPO). This database contains the world's most comprehensive collection of patent data, from major patent authorities, specific nations and proprietary source. The European classification (ECLA)[4] allocated 'B82' code for nanotechnology. It includes two sub-classes i.e. 'B82B: Nano-structures formed by manipulation of individual atoms, molecules, or limited collections of atoms or molecules as discrete units; manufacture or treatment thereof'; and 'B82Y: Specific uses or applications of nano-structures; measurement or analysis of nano-structures; manufacture or treatment of nano-structures'[5]. This classification code was used for extracting nanotechnology records from the EPO.

Indian Patent Office (IPO) grants and applications were captured through Indian Patent office (ipindia.gov.in) database and India.bigpatents.org. Two search strategies were used for extraction of patents from IPO i.e. a) due to searching limitation in the Indian patent database, elementary search string nano* was used for extracting nanotechnology patents. Nano* defines all prefixed terms and

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[2] Refer to Annexure III for detailed sub classification of nanotechnology for Class 977.

[3] The USPTO defines the term 'nanostructure' to mean an atomic, molecular or macromolecular structure that:
a) Has at least one physical dimension of approximately 1-100 nanometers; b) Possesses a special property, provides a special function, or produces a special effect that is uniquely attributable to the structure's nanoscale physical size.

[4] The European Classification System (ECLA) is an extension of the IPC and is used by the EPO. IPC codes which are maintained by the WIPO are closely related to ECLA codes of EPO.

[5] Refer to Annexure III for detailed sub classification of Class B82.

has been used earlier in harvesting nanotechnology publication (see for example Tolles, 2001; Meyer *et al.* 2001), and b) 'B82' class, identified as nanotechnology by the WIPO (World Intellectual Property Organization). CSIR is the most prolific organization in India in patenting activity and thus further examination of its nanotechnology patents were undertaken. CSIR has its own patent database Patstats (www.patstats.org/). Using the search strategy 'Nano*', nanotechnology patents filed/granted to CSIR were extracted. Cleaning was undertaken to remove noises as search based on the broad lexical quarry 'nano*' led to extraction of patents not connected to nanotechnology.

International standardization activity was captured through Technical Committee (TC) activity in nanotechnology identified by TC 229
(http://www.iso.org/iso/iso_technical_committee?commid=381983),
European Commission reports, country study reports, World Watch Institute report, etc. Indian standardization activity was captured by examining activities of the Bureau of Standards (India), CSIR-National Physical Laboratory, Nano Mission and activities of other key departments/ministries and published reports/papers.

Analysis of nanotechnology based products or product lines in the international market were identified through the Woodrow Wilson database. This database does not cover processes/applications and therefore it is inadequate in determining process inventory i.e. medical applications and other useful processes in different areas. However, no acceptable international database is available that covers processes/applications developed based on nanotechnology. In the domestic case i.e. within India it was possible to capture through secondary sources and primary survey the processes/application. Various secondary sources such as IBID (newspaper clipping service), annual reports, web-sites, trade-journals etc were used. Along with capturing additional items, primary survey also helped in validating the coverage from secondary sources.

1.4 Chapter outline

This report is organized in five chapters including this Chapter on Introduction. Chapter two underscores the complexity and challenges for nanotechnology development. It then focuses on the nanotechnology development in different countries. In doing so this chapter tries to tease out the priorities and pathways that some of the countries have undertaken to develop and adopt nanotechnology. Nanotechnology development in the USA, China and South Korea are examined in depth to uncover policies and strategies instrumental in the development of nanotechnology in each of these economies. This chapter also investigates ASEAN countries to understand nanotechnology development from a developing country point of view. Chapter three tries to capture India's nanotechnology initiative, its approaches, priorities, achievements, challenges and outcomes. Chapter four measures India's performance in nanotechnology, to assess to what extent the various initiatives the country has undertaken in this technology has led to tangible outcomes. Chapter five discusses the key findings of this study, brings together the lesson learnt and concluding remarks. Finally, it restates the strategic priorities that the study posits can strengthen the research and innovation activity in nanotechnology in India and lead to tangible outcomes.

2. Nanotechnology Development and Strategies

2.1 Complexity and Challenges for the Development of Nanotechnology

"Key challenges to nanotechnology governance include developing multidisciplinary knowledge foundation; establishing innovation chain from discovery to societal use; establishing an international common language in nomenclature addressing broader implications for society; and developing the tools, people, and organizations to responsibly take advantage of the benefits of the new technology"

Mihail C. Roco , NSF

Nanotechnology is knowledge intensive field which is highly interdisciplinary, capital intensive, and requires sophisticated instruments, and manpower with interdisciplinary competency. Interdisciplinarity implies that development in this field requires cross-fertilization of ideas from different disciplines. Developing nanotechnology capability requires scientific and technological capacity in material science, applied physics, applied chemistry, etc. Nanotechnology is strongly science based wherein 'technological success' increasingly depends on strong scientific capabilities and on the ability to interact with science and scientific institutions; requiring institutional mechanisms that can strengthen the academia-industry linkages. Nanotechnology is at an early phase of development with many applications still at the concept stage requiring much more basic research and incubation time before they can be incorporated into a viable product. Thus firms are reluctant to invest and devote R&D fund in this technology especially so in developing countries where private sector research is miniscule and investment is more towards adaptive R&D and development. The above characteristics make government stimulation a very important ingredient for developing capability in nanotechnology. The practical concerns in nanotechnology development therefore calls for strong government involvement as a key stakeholder in providing venture capital, creating institutions (research institutions, facilities, science parks, business ventures), facilitating linkages between various stakeholders (public private partnership) and catalyzing industrial activities (through conducive policies and lucid regulatory environment). This is more so for developing countries where the innovation ecosystem is still developing.

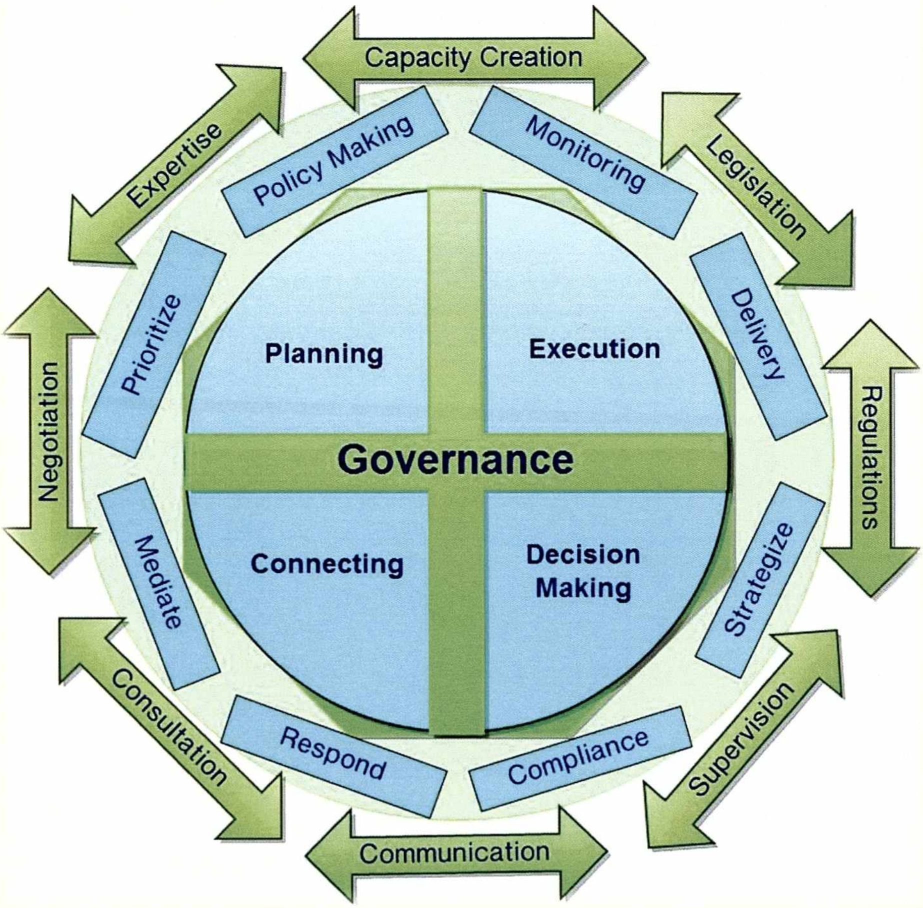
2.2 Nanotechnology Governance

"The benefits of nanomaterials can only be realised within a clear regulatory framework that fully addresses the very nature of potential safety problems relating to The Need for a Regulatory Framework for nanomaterials".

- European Parliament 2010

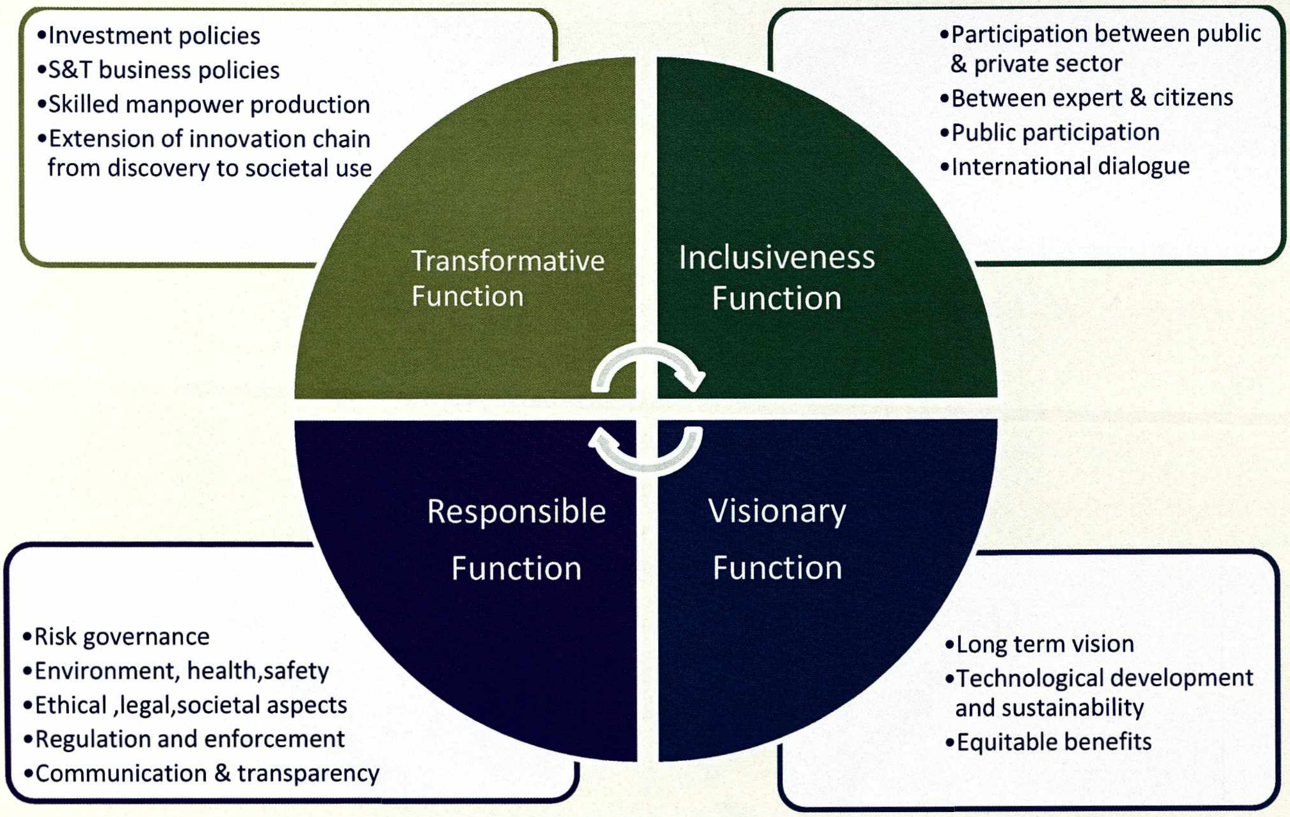
The close relation between technology and society implies that the task of governing a technology is not limited to just management and administration of resources, institutions and system associated with a technology. It includes structures and processes for collective decision making involving governmental and non-governmental actors, and integration of technological developments with societal needs. In other words, technologies need to be integrated in a given social, economic, political, industrial, environmental and ethical conditions. A regulatory environment needs to factor these issues while making legislation for controlling the role and action of various individuals and institutions. Figure 2.1 depicts various aspects of technology governance.

Figure 2.1: **Technology governance**



Nanotechnology governance primarily include developing knowledge base, developing innovation ecosystem, standards and patents, and creating the interface between the technology/expert and society at large that can help in 'proper' development and acceptance. Governance issues in nanotechnology have been raised by many scholars. Roco *et al.* (2011) has given a schematic outline which succinctly captures the different dimensions involved in nanotechnology governance (See Figure 2.2 below)

Figure 2.2: **Key aspects of nanotechnology governance**



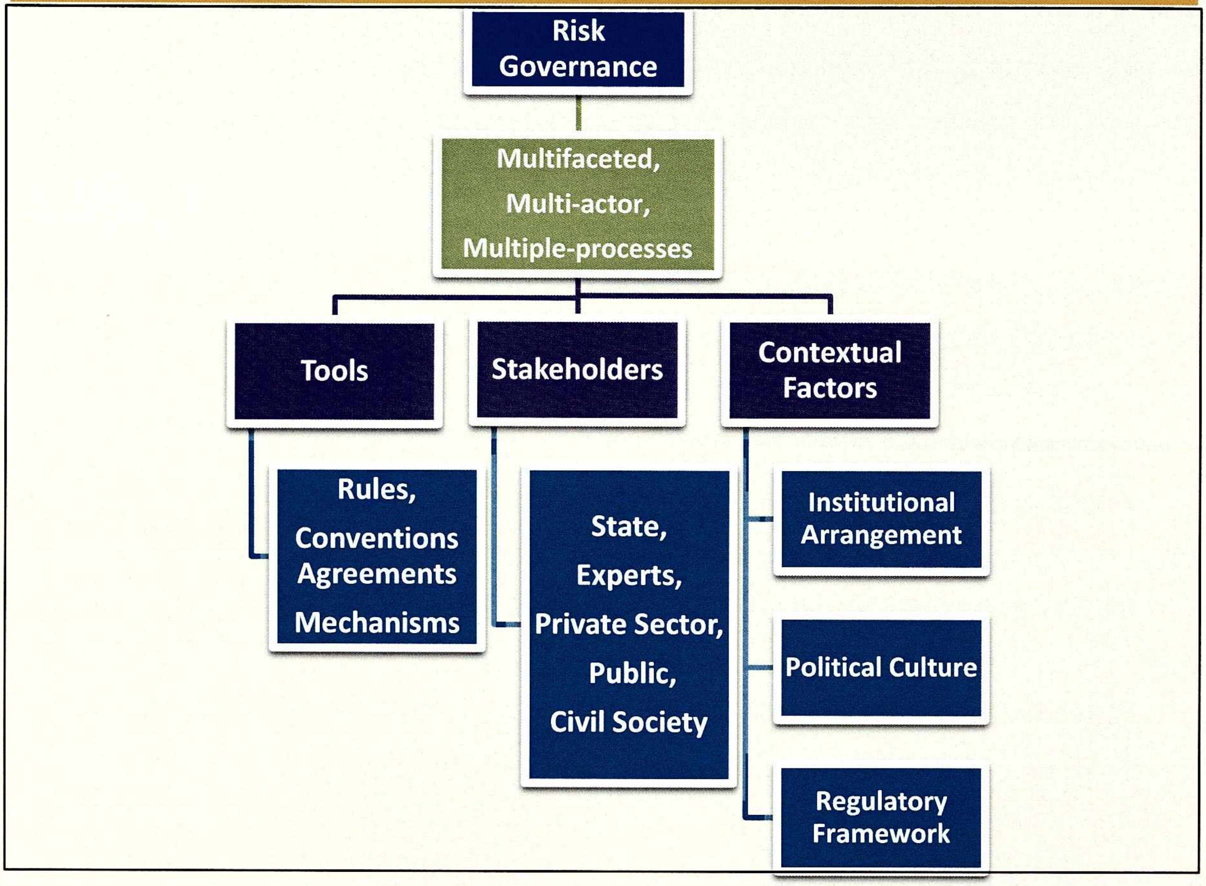
Source: Governance approach proposed by Roco et al. (2011)

The goal is to undertake Responsible technology development defined as a development approach that ensures equitable sharing of cost, benefits and responsibilities related to technology development among developers, promoters, government, industry and users.

2.2.1 Risk Governance

Risk governance is the application of governance approach to issues of risks and basically refers to the different ways in which various actors are dealing with them. Figure 2.3 shows possible stakeholders involved in risk governance framework.

Figure 2.3: **Technology risk governance**



Source: Author's own construction

Risk governance recognizes that decisions about issues of risks are not the exclusive domain of the government (van Asselt *et al.* 2011). The government is one of the major stakeholders but there are other stakeholders also who influence and are participants in articulation and implementation of the framework. The primary motive is to develop any technology in a responsible way so that it addresses economic and social welfare without any adverse implications. This applies more to nanotechnology, a key emerging technology which is at an early stage of development. Scientists and engineers, civil society and industry/industry associations are among the key stakeholders. Civil society organizations act as an interface between government and society. Companies also have economic interest at stake and thus are supportive of actions that can mitigate risks and make the technology acceptable. International organizations such as OECD and the ISO are also important stakeholders and naturally are concerned about mitigating nanotechnology risks as it can adversely impact upon its products and commercialization process. The risk governance framework draws attention to this multitude of actors and institutions. As a descriptive framework, it stipulates that the ways risks are dealt with cannot be understood without taking this complex field of actors into account.

The risks associated with nanotechnology are to a large degree characterized by technological uncertainty. For instance, some studies have demonstrated that nanoparticles can potentially pose risks for human health and environment, but to what extent they inflict harm and how they do so is not very clear. Contemporary observers have noted uncertainties in relation to both the risks and benefits that inevitably accompany new technologies often making standard forms of decision-making difficult and inadequate. Secondly, innovations in nanotechnology are likely to be incorporated across disciplinary and industrial boundaries. A wide range of sectors and consumers are thus likely to be affected. When focusing on the way risks are dealt with, these actors are likely to enter the arena and affect the way decisions are taken – whether it is through testing for risks, drafting legislation, or by simply not consuming nanotechnology products because of the potential risks. Some key reports have brought the risk mitigation in international debate and have influenced different countries to re-focus on their nanotechnology development and strategy.[6] Figure 2.4 and 2.5 highlights some of the concerns related to nanotechnology that emerges from different studies/reports.

[6] See for example Observatory Nano ETC report

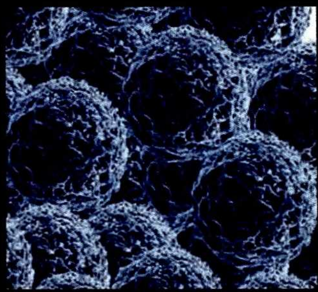
Figure 2.4: **Major concerns regarding nanotechnology**

Nanoparticles | **Impacts**

Nano Silver (Ag)

It is a disinfectant and has biocidal properties which is toxic to wide range of bacteria, fungi and algae

Applications: Used in water purifiers, Deodorants, washing Machines, refrigerators, Air conditioners, detergents and Anti-odour Clothing

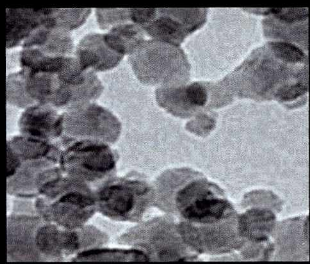


Nano Silver (Ag) particles can accumulate in the environment and contaminate soil and water

Titanium Dioxide

Nano Pigments such as Titanium oxide (TiO_2) and Zinc Oxide (ZnO) are used for their capacity to reflect and Scatter UV radiations

Applications: Used in Sunscreens, Lotions, Self Cleaning Paints and Coatings

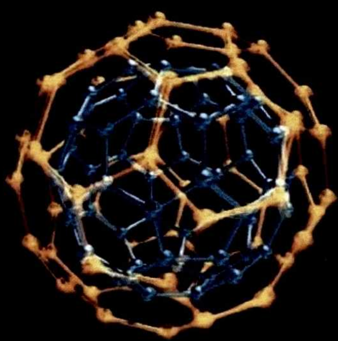


High concentration of and exposure to TiO_2 nanoparticles can cause genetic damage and oxidative stress

Fullerenes

Fullerene (0.7 nm) is a carbon allotrope including 60 carbon atoms (C_{60}). The unique structure of fullerenes allows it to bind to free radicals (molecules that cause oxidative stress, which experts believe may be the basis of ageing) also resists pressure deformation

Applications: It is used in Anti-ageing and Anti-wrinkle creams

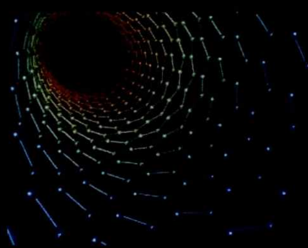


Have shown genotoxicity, induces DNA cleavage, mutation, cancer initiation, cell toxicity

Carbon Nanotubes

Carbon nanotubes (CNTs) are cylindrical carbon molecules and have extraordinary strength and unique electrical properties, and are efficient conductors.

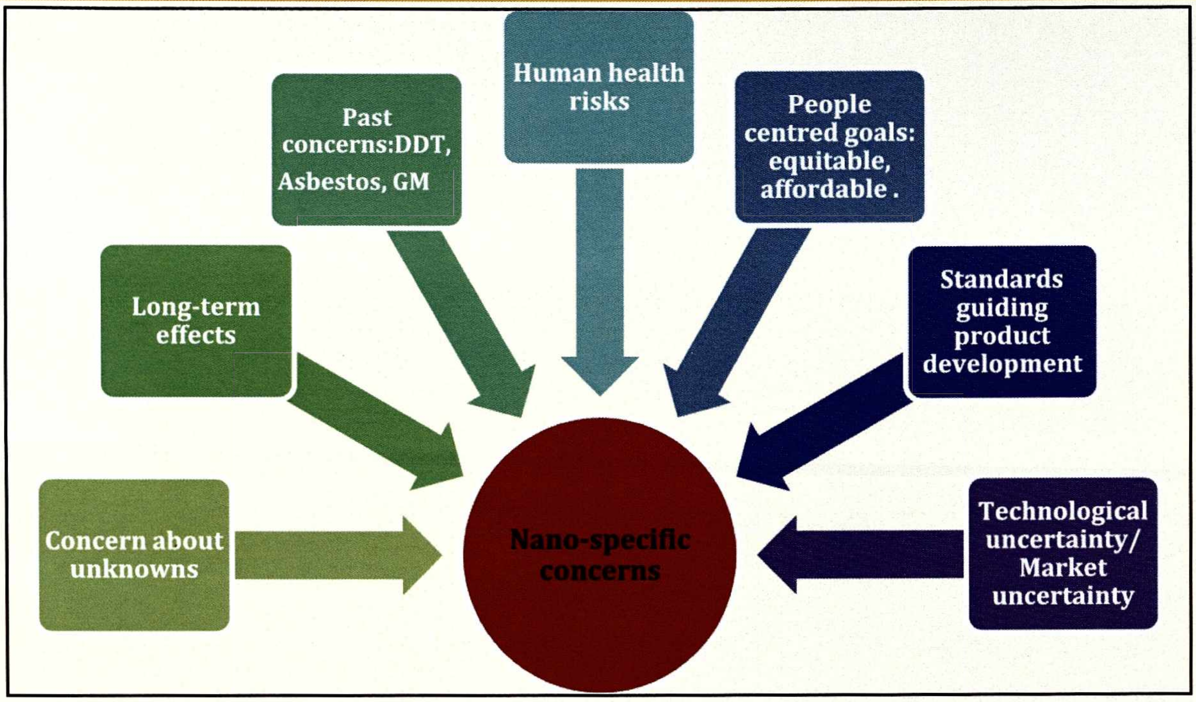
Applications: Tear Resistant Textiles, Stronger and Lighter Sport equipments and Targeted Drug delivery



Can cause cell and DNA damage and can cross the cell barrier

Source: Jayanthi et al. (2012), Oberdörster (2004); Gopal, V.S et al. (2008); Oberdörster (2000); Stern and McNeil (2007)

Figure 2.5: **Nanoparticles and their potential impacts**



Source: Author's own construction

2.2.2 Standardization

Standard creation in nanotechnology requires sophisticated metrology capability. Also when standards are internationally adopted, those involved in this process are better equipped to incorporate the accepted standard in their product/process.

Standards plays key role in innovation, diffusion and regulation. An area like nanotechnology in an early stage of development, standardization becomes key in defining the acceptable benchmarks, product/process development criteria's and provides 'early mover' advantage. Standards also act as a strategic instrument for those (countries, firms) that have early access or have been involved in their creation (in a particular product class) in influencing the market.

Standardization is a challenging activity and more so in nanotechnology. It calls for highly technical sophistication and understanding for measuring the phenomenon at the nano scale. Accurate measurement of the dimension and physical, chemical and mechanical properties of nanomaterials is highly complex activity because of their extremely small size and their minuscule response to any perturbation used to measure a property. As a result, the reported properties of these materials vary widely from group to group. It is a great challenge for the international bodies who work in the area of standards to devise ways for standardization of the properties of nanomaterials. The extremely high chemical activity of nanomaterials, because of the large surface – to - volume ratio, makes them hazardous to human health. This concern is not only for biological applications where these materials are injected into human body but also during manufacturing and large scale external use (Budhani 2011, Observatory Nano 2008).

Report by the Observatory Nano EU has identified some major complexities in formulating standards and implementing (Mantovani, *et al.* 2010): Wide variety of materials and applications in nanotechnology; Limited knowledge on the toxic effects of nanomaterials in living systems and their transport in living and environmental systems; The proprietary nature of information on novel nanomaterials is making access difficult to relevant information; The lack of harmonized standards or guidance; The potential inadequacy of statutory authorities

International Organization for Standardization (ISO) Technical Committee (TC) 229 is responsible for developing international guidelines for nanotechnology. The ISO has categorized nanotechnology standards in four TC's working groups: WG1-'Terminology and Nomenclature', WG2- 'Measurement and Characterization', WG3- 'Health, Safety and Environment', and WG4- 'Material specification'. Scope of ISO TC 229 includes standardization in the field of nanotechnologies, understanding and control of matter and processes at the nanoscale, typically, but not exclusively, below 100 nanometres in one or more dimensions where the onset of size-dependent phenomena usually enables novel applications, utilizing the properties of nanoscale materials that differ from the properties of individual atoms, molecules, and bulk matter, to create improved materials, devices, and systems that exploit these new properties, specific tasks include developing standards for: terminology and nomenclature; metrology and instrumentation, including specifications for reference materials; test methodologies; modelling and simulations; and science-based health, safety, and environmental practices.

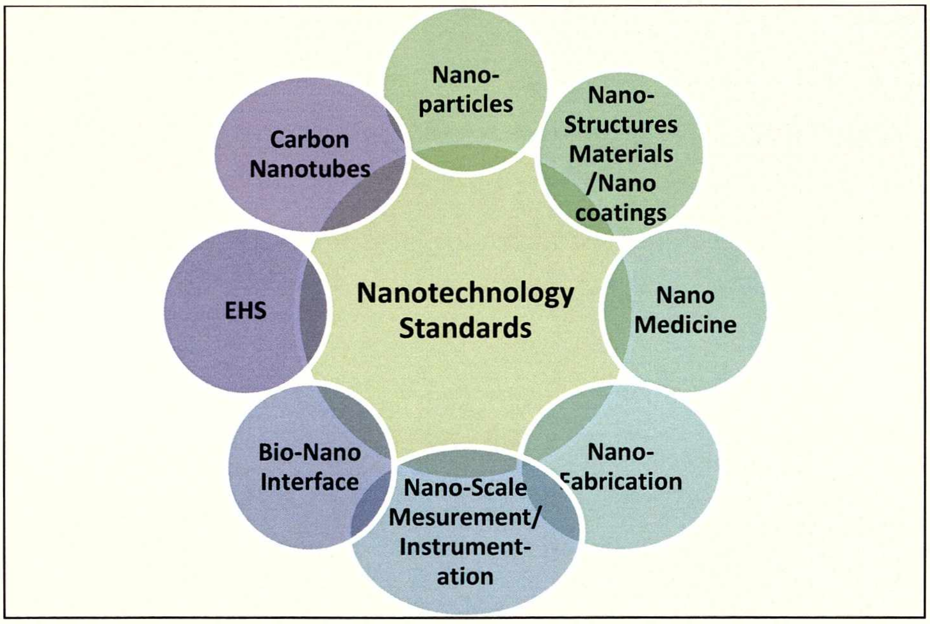
Table 2.1: **Countries participating in TC229**

Secretariat	**1**	**United Kingdom, BSI**
Participating countries	34	Australia (SA), Austria (ASI), Belgium (NBN) ,Brazil (ABNT), Bulgaria (BDS), Canada (SCC), China (SAC), Czech Republic (UNMZ), Denmark (DS), Finland (SFS) , France (AFNOR), Germany (DIN), India (BIS), Indonesia (BSN), Iran, Islamic Republic of (SIRI), Ireland (NSAI) , Israel (SII), Italy (UNI), Japan (JISC), Kenya (KEBS), South Korea, (KATS), Malaysia (DSM), Mexico (DGN), Netherlands (NEN), Norway (SN), Poland (PKN),Russian Federation (GOST R), Singapore (SPRING SG), South Africa (SABS), Spain (AENOR), Sweden (SIS), Switzerland (SNV), USA (ANSI)
Observing Countries	12	Argentina (IRAM), Egypt (EOS), Estonia (EVS),Greece (ELOT), Hong Kong, China (TCHKSAR) *(Correspondent member),* Kazakhstan (KAZMEMST), Morocco (IMANOR), Portugal (IPQ), Romania (ASRO), Serbia (ISS), Sri Lanka (SLSI), Thailand (TISI)

Note: Each country is qualified by the institute involved therein in developing standards

Nanotechnology standards also have complex linkages with other standards. Figure 2.6 illustrates the TC-229 and its focus areas.

Figure 2.6: **Nanotechnology TC 229 and its focus areas**



Source: Constructed from TC 229 documents

European Union is also working towards developing standards for nanotechnology. Under European Union detailed framework for regulation as articulated by REACH (Registration, Evaluation, Authorization and Restriction of Chemicals) special attention has been paid on standardization in the following areas: (1) Chemicals and materials (2) Cosmetics (3) Foods (4) Occupational health and worker safety (5) Environmental safety (6) Medical devices and pharmaceuticals. Medical devices using nanotechnology are covered under specific European Commission Directives-Medical Devices Directive 93/42/EEC (MDD), the Active Implantable Medical Devices Directive 90/385/EEC (AIMDD) and the In Vitro Diagnostic Medical Devices Directive 98/79/EC (IVDD). Current EU legislative framework covers, in principle, the potential health, safety and environmental risks. Further modifications of current regulations as the scientific knowledge on nanomaterials increases are required.

2.3 Nanotechnology Development : Different Country Approaches

2.3.1 Role of Government

The US government initiated a multi-agency nanotechnology program called 'National Nanotechnology Initiative' (NNI) in 2000, which provided a comprehensive framework for developing nanoscience and nanotechnology. The strong argument for nanotechnology as a key technology of the future articulated by the USA stimulated other countries to put nanotechnology as a major agenda within their S&T program and policies. Research in nanotechnology became a more coordinated/mission oriented activity in majority of countries from the earlier disparate activity influenced primarily by NNI. It led to advanced OECD economies, BRICs (Brazil, Russia, India and China) and other developing economies articulating specific mission programs, and devoting considerable funding to create research capacity. Among BICs, Brazil has invested US $200 million till date, articulated a fifteen year industrial nanotechnology plan to help commercialize products leveraging nanotechnology, and has created a nanotechnology network for linking research institutes and universities. India's ongoing Nano Mission initiated in 2007 with an allocation of USD250 million for five years, is focusing on basic research, infrastructure development, commercialization, education, and international collaboration. This effort is supported by other scientific agencies through their own dedicated funding and programs. China has already made significant investment resulting in some tangible achievements. Table 2.2 provides an overview of the nanotechnology initiatives by some developed and emerging economies.

Table 2.2: **Nanotechnology government initiative and investment in some of the major economies**

	Key Coordinating Body	Nanotechnology Initiative (Year of Commencement)	Funding	Key Areas
US	Multiagency Governance at Various Levels. Command and Control Mode. Nanoscale Science Engineering and Technology Subcommittee	National Nanotechnology Initiative (2000)	USD 1.5 billion in 2009	All aspects of nano-technology
Japan	No Specific Coordinating Body	The Atom Technology Program (1992) Nanotechnology and Materials Program (2001)	USD 250 million	Nano-electronics, nanomaterials
South Korea	Ministry of Education, Science and Technology, Ministry of Knowledge Economy	Korean National Nanotechnology Initiative (KNNI),2001-05 (Phase I), 2006-10 (Phase II)	2001- 10 USD 2 billion.	ICT applications, e.g. high density memory, displays
Taiwan	National Science Council, Department of Industrial Technology	Taiwanese National Nanotechnology Program 2003 (Phase I), 2009-14 (Phase II)	USD 550 million USD 685 million.	ICT applications primarily opto-electronics
China	National Steering Committee for Nanoscience and Nanotechnology	National Steering Committee for Nanoscience and Nanotechnology (2000)	2001-05 USD 250-300 million. 2006-10 USD 760 million.	Nanomaterials, and ICT applications

	Key Coordinating Body	Nanotechnology Initiative (Year of Commencement)	Funding	Key Areas
India	Multi-agency DST (Initiation & implementation of NSTI & Nano Mission) DIT, DBT, CSIR, DRDO, ICMR, ISRO, DAE	Nano Science and Technology Initiative (2001-06) Nano Mission (2007-12) DIT Nanoelectronics initiative 2004 onwards	USD 16 million (NSTI) USD 250 million (Nano Mission)*	Nanomaterials, biomedical, electronics, energy (solar), water

***Note**: Funding figures are approximate (as given approximately or due to conversion). The above table highlights the formal start of nanotechnology programmes in different countries. However, these countries had activities and directed programmes in Advanced Smart Materials, Macro Electro Mechanical Systems (MEMS) etc., which were the follow ups to the nanotechnology programmes as highlighted in the table.*

**100 crores (INR) ≈ 27 million USD. The total expenditure in nanotechnology so far of other scientific departments/agencies including NSTI and Nano Mission of which figures are available is Rs. 973.37 crores (approx. 263 million USD).*

2.3.2 Human Resource Development

Nanotechnology derives from different disciplinary streams i.e. highly interdisciplinary unlike other knowledge intensive areas where a strong driving disciplinary field can be discerned (for example biotechnology, speciality chemicals,…).Thus developing manpower in nanotechnology is a complex task as it requires not only the understanding of a particular domain but also require integration from other disciplines. Scientometric analysis has shown key fields of research activities that influences nanotechnology research. These key fields are: Material science, Chemistry, and Applied Physics. Plausibly keeping this complexity in consideration, USA as well as in other advanced OECD countries, nanotechnology specific university level degrees are not prominently visible. Analysis of research reports show that different countries are reorienting their courses for instance in material sciences, condensed matter physics and applied chemistry with an introduction to nanotechnology. Nanotechnology emerges as a specific domain in post-graduate (as separate programme or part of specific disciplinary programme) and in doctoral programmes and research. Thus it is not possible to properly estimate the human resource developed in nanotechnology in different countries. India's nanotechnology expert C N R Rao, who is also the chairman of Scientific

Advisory Council to Prime Minister, echoes a similar view "Students should first opt for a degree in any stream of engineering before going in for specialization in nano-research or technology".[7] Nanotechnology centers with industry involvement have been created in different countries. These centers are active breeding ground for development of skilled manpower. They also act like finishing schools. Students are exposed to sophisticated instruments, they learn how to use these instruments, work with key researchers and other specialists who are involved in developing applications from the scientific research and invention carried out in these centers. It also helps the students coming from a particular disciplinary stream to interact with others who are from different academic backgrounds. This helps in the learning process and embeds in students the skills of different fields.

2.3.3 Nanotechnology Risk Governance: Different Country Approaches

Considering the risks posed by nanotechnology, different countries have come up with their own risk governance approaches. Table 2 .3 shows key risk regulation strategies adopted by different countries.

Table 2.3: **Initiatives by different countries in addressing nanotechnology risk governance**

Country	Major Public Promoting/Supporting Bodies	Key Legislations/ Code Of Practices/Institutions created
USA	National Level (National Science Foundation) –Research Regulation. (Presidential Council of Advisors on Science and Technology)- Nanotechnology Initiative Review. Agency Level Food and Drug Administration, National Institute for Health, National Institute for Occupational Safety and Health, Nanotechnology Environmental and Health Implication Working Group Program Level (Committee of Visitors)- Evaluation through Stakeholder Inputs (Advisory Boards)-R&D Programs Review	Nanotechnology Research and Development Act (2003) Food Drug Cosmetics Act Toxic Substance Control Act (2005) Occupational Safety and Health Act.

[7] The Times of India, June 21, 2012
http://articles.timesofindia.indiatimes.com/2012-01-21/hyderabad/30650502_1_nano-technology-nano-research-nano-mission-council

Country	Major Public Promoting/Supporting Bodies	Key Legislations/ Code Of Practices/Institutions created
UK	Nanotechnology Research Coordinating Group, Department for Environment, Food and Rural Affairs, Department of Health, Food Standards Agency, Learned Societies, The Royal Academy of Engineering, The Institute of Materials Minerals And Mining, UK Programme of Public Engagement on Nanotechnologies, Nanodialogues	Guide to Safe Handling and Disposal of Free Engineered Nanomaterials Guide to Specifying Nanomaterials Good Practice Guide for Labeling of Nanoparticles and Products Containing Nanoparticles
European Nations	European Commission	Registration, Evaluation, Authorization and Restriction of Chemicals (REACH) REACH Regulation 1272/2008 on classification, labelling and packaging (CLP) of substances and mixtures
Japan	National Institute of Advance Industrial Sciences, National Institute of Material Sciences	Chemical Screening and Regulation Law
China	Ministry of Science and Technology Ministry of Education Chinese Academy of Sciences National Natural Science Foundation of China	Technical Standardization Committees Committee on Nanotechnology Standardization (SAC/TC279). Lab for Bio-Environmental Health Nanosafety lab

Country	Major Public Promoting/Supporting Bodies	Key Legislations/ Code Of Practices/Institutions created
India	NIPER developing regulatory approval guidelines for nanotechnology based drugs and standards. CSIR for safety and toxicological standards. ICMR: Standardization in medical nanotechnology interventions. DST (Nano Mission) and DBT: funding support for toxicology studies.	In 2010, DST appointed a task force which has been asked to advice Nano Mission Council to develop a regulatory body for nanotechnology in India

Source: Jayanthi, Beumer and Bhattacharya (2012); Observatory Nano (2010)

The issue of risk and uncertainty has been addressed at the national level by countries in different ways ranging from allocation of dedicated fund for EHS/ELSI research (for example US has devoted about 7% of its budget for Nano environmental health and safety concerns) or strong focus on public dialogue (Netherland initiative) or creating dedicated centers for risk research (for example China has created specialized institutions for risk management and funding for EHS research). There have been other initiatives also such as introduction of nanomark certification by Taiwan which authenticates the safety of the nanotechnology based product.

EU is trying to develop 'early warning systems' for risk assessment. It is developing a governance framework that is adaptive. In Netherlands a novel initiative was undertaken to bridge the public uncertainty. For this an independent Committee for the Societal Dialogue on Nanotechnology in the Netherlands (CMDN) was created to stimulate debate on nanotechnology and develop public opinion in this area, more specifically on the social and ethical issues involved. While the debate on nanotechnology, its opportunities and risks, has been going on for a number of years, but was limited to specialists and organizations. Dutch government initiative was novel as it decided to stimulate a broader societal dialogue by involving individuals and organizations to propose activities to stimulate the dialogue in which different views can be expressed freely.[8] This led to wider dissipation of knowledge about nano amongst Dutch public (including the potential benefits, increased recognition of risks involved, and increased support for continued research into nano with responsible technology governance).

[8] http://www.oecd.org/science/safetyofmanufacturednanomaterials/47556265.pdf .

UK is making an early public engagement in defining R&D problem in nanotechnology. It is trying to develop regulatory guidelines at the early stage of research promotional policy.

2.4 US Strategies for Nanotechnology Development

US strategy plan for nanotechnology includes increased funding for R&D, strengthen the educational resources, increase in commercialization of nanotechnology, and supporting the responsible governance of nanotechnology.

It is important to investigate US nanotechnology initiative as its mission oriented nanotechnology program has been the key stimulant for world-wide interest and investment in this area. The model and roadmap articulated by the US nanotechnology initiative has found reflection in programs created by different countries for nanotechnology development. Thus it becomes imperative to underscore the key aspects of US nanotechnology initiative.

Some of the salient aspects of US nanotechnology development are: The United States invests more money in nanotechnology R&D than any other country—a total of $5.7 billion in 2008. From 2003 to 2008, U.S. public and private investments in nanotechnology grew at 18 percent annually. U.S. research is still more likely to appear in high-quality publications, as assessed by citation indices. The United States is the world leader by a large margin in the absolute number of nanotechnology patents issued The United States produced a reported $11 billion worth of nanotech components for use in commercial products out of a reported worldwide total of $29 billion in sales.

Table 2.4: **Nanotechnology development in the USA**

Nanotechnology Model	National Nanotechnology Initiative (NNI) is a federal nanotechnology R&D program. It is a multi-agency initiative involving 25 Federal Agencies and wide Industry representation.
Policy Actions	• 21st Century Nanotechnology Research and Development Act (Public Law 108-153) enacted in 2003 dedicated to R&D and societal dimensions of nanotechnology. • Department of Defence participation in the NNI separately established by Public Law 107-314. • National Institutes of Health has special legislation from congress. Congress issues authorization laws and funding appropriations for nanotechnology R&D by federal agencies participating in NNI each year.

Direction of Funding and New trends	• The 2013 budget includes nearly \$1.8 billion for nanotechnology R&D, a 4% increase over 2012. Cumulative investment of \$18 billion since NNI's inception in 2001. • The NNI agencies are focusing on building and sustaining infrastructure through support for research facilities, acquiring the instruments to do the work of nanotechnology, and strategic investments to improve ability to manufacture materials at the nanoscale and to manufacture products containing nanomaterials. • NNI manufacturing and job creation focus reflected in budget for Financial Year (FY) 2013 • Key areas of nano-manufacturing and infrastructure have been given importance in Nation's ongoing economic recovery and future growth as part of a new innovation economy. e.g. President's Advanced Manufacturing Partnership and the Materials Genome Initiative. • While fundamental research remains the largest single NNI investment category (\$498 million in the 2013 budget), the more applied research in Nanodevices and systems and in the nano-manufacturing now total over \$500 million combined, as some areas mature and applications develop. • NNI investments in instrumentation research, metrology, and standards and in major research facilities and instrumentation are sustained at about \$70 million and \$180 million, respectively, during 2011-2013. • 2013 Budget includes over \$300 million in funding for the three National Signature Initiatives that were introduced in the 2011 Budget: \$112 million for Nanotechnology for Solar Energy Collection and Conversion; \$84 million for Sustainable Nano-manufacturing; and \$110 million for Nanoelectronics for 2020 and beyond. This represents a 24% increase in NSI investment compared to 2011 actual spending.
Industry Involvement from Lab to Market	• National nanotechnology centers have been created that allows access to industry for R&D, and also provide academia-industry linkage. The 'Nano-manufacturing, industry liaison, and innovation (NILI) working group' is a key institution for promoting and facilitating nanotechnology innovation and to improve technology transfer to industry. It also promotes interagency cooperation in the areas of standards, nomenclature, nano-manufacturing research and use of programs that encourage innovation in small business. Apart from this, Federal Government's created specialized centers for promoting Technology Transfer, for example: The Robert C. Byrd National Technology Transfer Center (NTTC), The Federal Laboratory Consortium for Technology Transfer, The Agricultural Research Service is also actively involved in nano technology transfer.

	Industry has taken its own initiative for commercialization of nanotechnology by creating Nano Business Commercialization Association.

Source: Constructed from www.nano.gov/ (various publications cited within this site); Office of Science and Technology Policy (US Government)

Box 2.1: **Industry-Government Partnership in USA in Nanotechnology- A Typical Example**

The Nanomanufacturing Industry Liaison and Innovation (NILI) working group was created to enhance collaboration and information sharing between U.S. industry and government on nanotechnology-related activities to advance and accelerate the creation of new products and manufacturing processes derived from discovery at the nanoscale. It also facilitates federal, regional, state, and local nanotechnology R&D and commercialization activities. In addition, the

NILI working group is trying to create innovative methods for transferring federally funded technology to industry. The NILI working group has facilitated collaborations between the NNI and the semiconductor/electronics industry, chemical industry, forest products industry, and the Industrial Research Institute. It facilitates the development of programs on nanomanufacturing R&D across the federal agencies and the private sector, in order to speed the widespread application of nanotechnology innovations into new and improved products and services for commercial and public benefit. It also assists industry-led partnerships—including Consultative Boards for Advancing Nanotechnology (CBANs)—between the NNI and industry sectors. Formation of a CBAN or other liaison group is open to any industrial sector.

U.S. leadership and participation in the international standards-setting process allows the United States to help shape the strategic and technical direction of nanotechnology development everywhere. U.S. Federal research related to measurement within science and technology is led by the National Institute of Standards and Technology (NIST). The standards community is actively involved in nanotechnology standardization, including ASTM International's Committee E56 on Nanotechnology and the American National Standards Institute (ANSI)-accredited U.S. Technical Advisory Group (TAG) to ISO TC 229, Nanotechnologies. ANSI administers the U.S. TAG to ISO TC 229, which is responsible for formulating positions and proposals on behalf of the United States with regard to ISO standardization activities related to nanotechnology. The United States holds the leadership of the ISO/TC 229 Working Group on Health, Safety, and Environment.

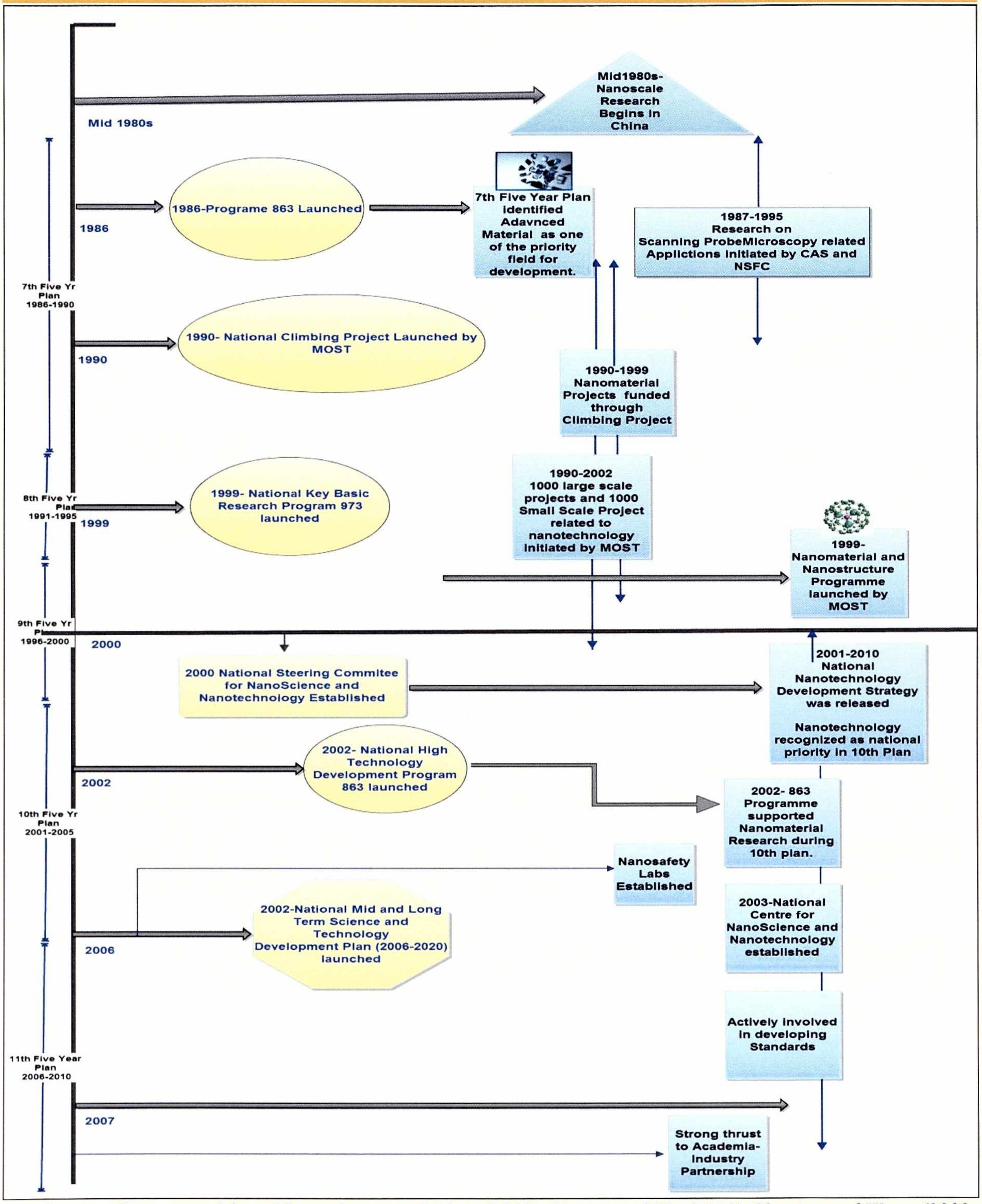
2.5 Chinese and South Korean Strategies for Nanotechnology Development

China and South Korea has made significant progress in nanotechnology. China within a ten year period (2000-2010) has become the leading country in nanoscience publications. It also holds the maximum number of standards in nanomaterials. Along with Hon Hai Precision (a global electronic component entity of Taiwan) it has filed maximum number of patents in the US Patent Office. South Korea in less than three decades transformed itself into an innovation leader. It is one of the global leaders in high-technology information technology (IT) products and components, automobile, shipbuilding. This remarkable transformation within a short period by South Korea created a widespread academic and policy interest to learn how this happened. Its nanotechnology development is also interesting as it is among a few countries which have taken a lead in translation of nanotechnology research to commercial application. Countries particularly emerging economies such as BRICS countries have made substantial progress in nanotechnology research but are able to exploit this for developing novel applications only to a limited extent. Investigating Chinese and South Korean progress in nanotechnology becomes important in this context as it can inform the strategies adopted by them in developing capability. This is very important for countries like India which is articulating a roadmap for nanotechnology development that can lead to value added products and also address developmental challenges by creating competitive edge for its firms and making its academic research more focused and coordinated.

2.5.1 Nanotechnology Development Strategy in China

China had made an early commitment in this technology as early as 1990, investing over 1.5 billion Yuan (approx. 228 million USD) during the period 2001 to 2005 and 5 billion Yuan (approx. 760 million USD) between 2006 and 2010. Among its key initiatives was the thrust on development of indigenous instruments for nanotechnology research. This led to the development of sophisticated instruments (Atomic Force Microscope (AFM), Scanning Tunnel Microscopy (STM)). These sophisticated instruments helped researchers to undertake more extensive and accurate research, for example improved nonmaterial characterization a key component of nanomaterial research. Another characteristic of Chinese capacity development has been the thrust on standard development and creation of technical standardization committees and Health, Safety and Environment institutions. Figure 2.7 depicts the Chinese nanotechnology roadmap.

Figure 2.7: **China nanotechnology strategy**



Source: Constructed from Bhattacharya and Bhati (2011), Huang and Wu (2010), Shapiro and Wang (2009; Note: National Key Basic Research Program was supported by the Program 973

Table 2.5: **Lessons from China's nanotechnology development**	
Creating a Niche	• Starting nanotechnology program very early i.e. 1990s. • Among its key initiatives was the thrust on development of indigenous instruments for nanotechnology research. This led to the development of sophisticated instruments Atomic Force Microscope, Scanning Tunnel Microscopy. • Sophisticated instruments provided researchers to undertake more extensive and accurate research, for example improved nonmaterial characterization a key component of nonmaterial research.
Technology Specific Policies	• The 863 program launched during the start of the 7th plan (1986-1990) identified advanced materials as one of the six priority fields. • In 2001 the Chinese Ministry of Science and Technology, and other key national S&T bodies issued a Compendium of National Nanotechnology Development (2001-2010). • 973 program and Torch program provide key thrust to basic research in nanomaterials and nanostructures and development of new and high technology industries and commercialization.
Coherence between Micro and Macro Policies	• China has taken a number of policy initiatives at different levels and articulated strategies and governance mechanism for implantation. • Local state governments also play an important role in implementing the national programs and also create their own programs and policies to enhance capability and capacity
Planned Move	• Unlike OECD economies, government funding extends across the value chain, from fundamental research to commercialization. • China has long term strategies for 'high technology' It is looking to future generations with plans to create awareness of the importance of nanotechnology in primary and secondary schools, as well as offer courses intended to prepare a new generation of scientists and engineers in this. • Government is playing the role of central actor in seed stage financing that makes attractive proposition for firms to carry forward technologies development from research labs and universities; helping bridge the gap between pure research and the product development stage.
Early Entry as Regulator	• China has created technical standardization committees and health, safety and environment institutions. In 2005 it created a committee on nanotechnology standardization (SAC/TC279) for drafting essential nanotechnology standards. • China is among a few countries that has developed standards in this area. It is chairing one of the four working groups WG4 of ISO/TC 229 for development of nanotechnology standards.

One of the features of China's nanotechnology development has been its strong focus on standardisation activity. China has developed a range of standards; initiating this process from 2003 onwards with different agencies involved in this process. In fact China was the first country to issue national standards for nanotechnology in April, 2005. Standard setting has been undertaken in parallel with other activities undertaken by China so as to gain early mover advantage in this technology. China has created 27 Nano-dimensional material and characterization standards, two standards on terminology & nomenclature and 12 nano materials/products standards. Twenty one standards have been implemented so far. China's active involvement in standard creation and adoption in nanotechnology is not surprising as it is a component of its overreaching strategy for future technology domination in this critical field. Standard setting has been undertaken in parallel with other activities undertaken by China so as to gain early mover advantage in this technology (Sleigh and Lewinski, 2006).

Box 2.2: **Industry-University Partnership in China in Nanotechnology**

Functional linkages are developing between university and industry in China. In national innovation systems of advanced OECD economies this is one of the key features which distinguish them from emerging economies. Science parks, incubation centers, industry created centers in universities; clusters are some of the common approaches adopted for creating these types of linkages. However, functional linkages must overlay infrastructural facilities or structural arrangements for academia-industry linkages to succeed which is missing in many of these types of arrangements. This is more so in these types of institutional arrangements in emerging economies as more stress is given for developing structural characteristics. China has been able to create these types of functional linkages in its nanotechnology development. It is already leading to tangible outcomes as seen from the case study of Tsinghua university (leading university in China, part of their top C9 university) and Hon-Hai Precision (a Taiwanese enterprise cited as world's largest electronics component manufacturer, which goes by the trade name Faxconn). In the campus of Tsinghua University, Hon- Hai Precision has opened a nanomaterials center 'The Tsinghua – Foxconn Nanotechnology Research Center (TFNRC)'. This center concentrates on application of carbon nanotubes, backed up by basic research. Tsinghua University has its own science park where these industrial arrangements are located. This park is inside Zhongguaancun Science & Technology park which is home to more 14,000 technology companies, 57 national-level labs, 29 national engineering and technology research centers, 17 university-affiliated science parks and 29 start-up parks for overseas returns.

Thus this centre (TFNRC) by this co-location enjoys access to varied types of linkages (academia-academia, academia-industry etc). The success of this centre can be seen from its patenting activity and applications development. It has filed more than 1000 patents in different patent offices and granted over 300 patents, and is the highest joint filing entity (Tsinghua–Hon Hai Precision) in the US patent office in nanotechnology. It has created proprietary nanotechnology based applications such as electromagnetic shielding, field emissions, touch panel screens that is now visible in high end products.

China is one of the leading countries in nanomaterial research and applications. This has been possible due to key policy actions and implementation (see Table 2.5). Some of the major achievements of their policy efforts have been creation of indigenous instruments, development of standards in nanomaterials and application (nanomaterial based textile embedding), risk assessment centers, nanotechnology centers with strong industry interface. Some of its key research outcomes are in development of carbon nanotube based applications. It was successful in creating the world's smallest carbon nanotubes (0.5nm in diameter) in 1999. Tsinghua University made yarns out of carbon nanotubes. After appropriate heat treatment, these pure carbon nanotube yarns have possibility of being woven into a variety of macroscopic objects for different applications, such as bulletproof vests and materials that block electromagnetic waves.

Institute of Metal Research in Shenyang discovered the superplastic property of nanostructured copper in 2002. Copper with these nanoscale structural motifs has a tensile strength about 10 times as high as that of its conventional counterpart, while retaining electrical conductivity comparable to that of pure copper. Fudan University demonstrated a general synthetic strategy for creating stable multi-component materials—such as mixed metal phosphates, mixed metal oxides, and metal borates—featuring a variety of porous structures. Such materials could lead to new families of catalysts, environmental filtration devices, and other technologies that rely on molecular interactions occurring in tiny nanoscale spaces.

Early involvement in basic nano-materials research primarily in coatings and composites and strong government funding to strengthen this area has helped in China's emergence as a major global player in this domain.

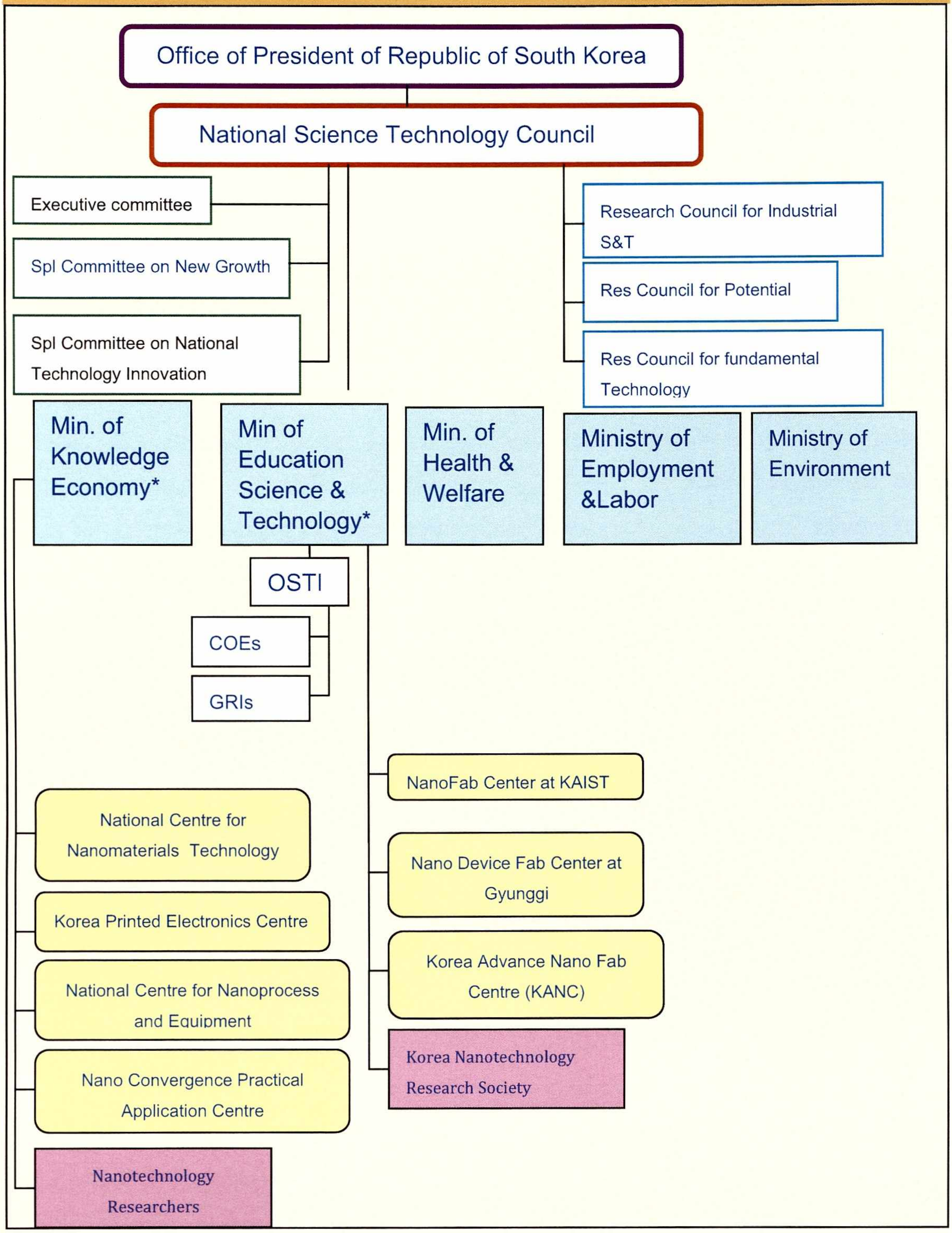
2.5.2 Nanotechnology Development Strategy in South Korea

South Korean nano-technology development strategy is a government-led mobilization of strategic resources for creating the nano-technology innovation ecosystem. There has been a strong focus on lab to market embedded in its nanotechnology program. Another key feature of their nanotechnology development is their efforts to develop convergence with other key frontier areas biotechnology and Information Technology.

South Korea commenced its national initiative for nanotechnology development in 2001. Korean National Nanotechnology Initiative (KNNI) as it later came to be known was grounded on a long term government policies, funding, infrastructure and manpower development since the late 1990's. Nanotechnology is identified as one of the six important fields to achieve technology led economic development in South Korea. At the heart of the KNNI is a long term plan Vision 2025, abiding to which it is pursuing capacity creation, commercialization of nanotechnology and international cooperation. Capitalizing on its strength in high technologies such as semiconductor memory chips and electronic products it is trying to develop nanotechnology infrastructure and focusing on core areas having commercial potential to keep up with the global trend in favor of the next generation technology. Figure 2.8 highlights the nanotechnology governance structure in South Korea.

It can be seen from South Korean nanotechnology governance structure (Fig. 2.8) that nanotechnology programme and plans of action are decided at the highest levels. This helps to provide coordination and horizontal linkages with different scientific agencies involved in nanotechnology development in South Korea. The key ministries engaged in nanotechnology development in Korea are MOST (Ministry of Science & Technology), Ministry of Commerce Industry and Energy (MOCIE) and Ministry of Information & Communication (MOIC). MOST is responsible for implementing the national coordination of S&T efforts within the country. It oversees compliance with the various national initiatives and coordinates national nanotechnology development, support mid- and long-term R&D activities for Nano Science and Technologies and supports establishing infrastructures for Nanotechnology Nanofabrication centers. MOST also coordinates Centers of Excellence (COE) in Korea, including: Science Research Centers (SRCs), Engineering Research Centers (ERCs), Medical Science and Engineering Research Centers (MRCs),

Figure 2.8: **Nanotechnology governance structure of South Korea**



** Merging of MOCIE and MIC **Previously MOST*

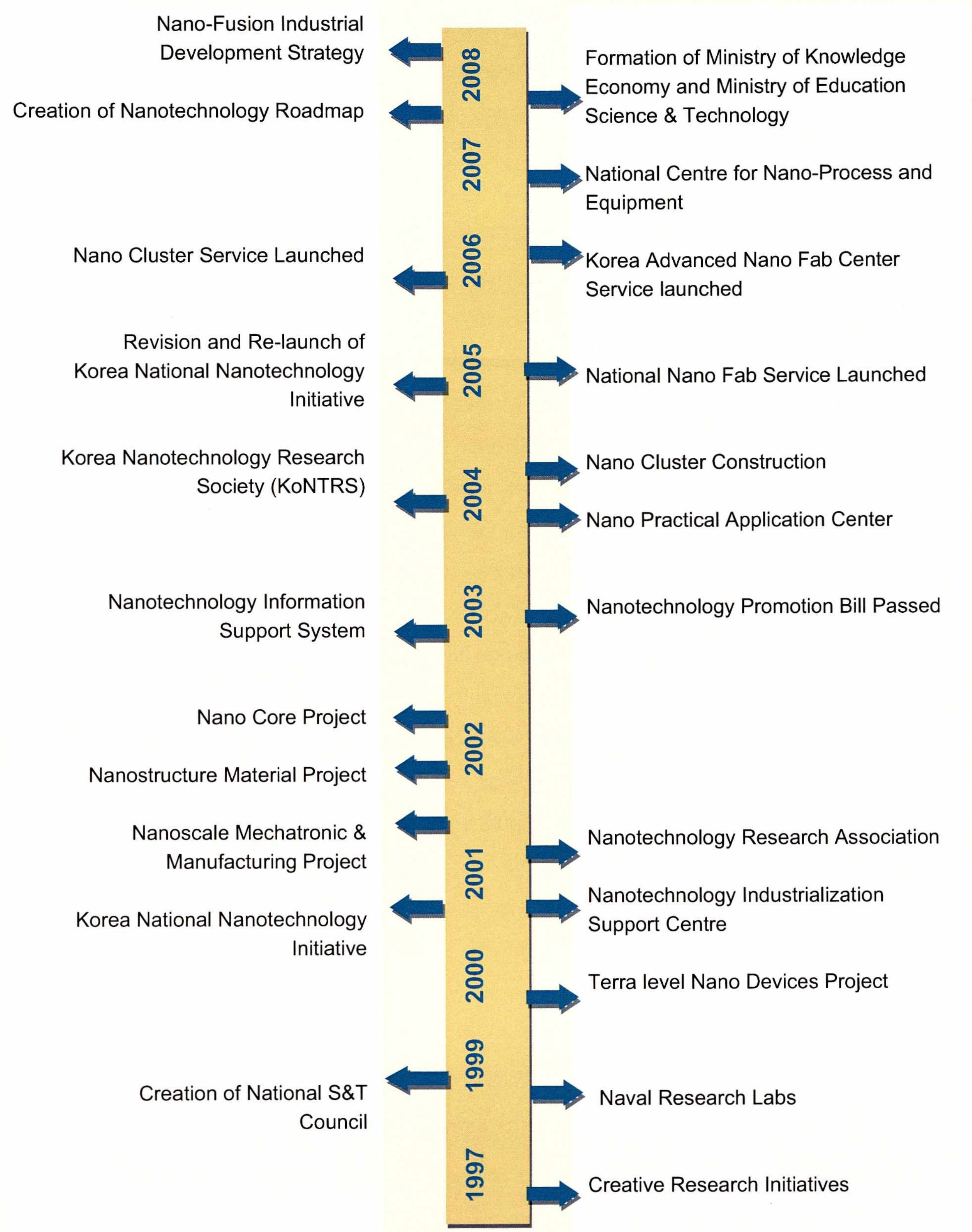
and National Core Research Centers (NCRCs). The NCRCs started in 2003 and currently have research centers on nano-application, environment and biotechnology, bio-dynamics, and nano-medical systems. GRIs (Government Research Institutes) most notably Korea Advanced Institute of Science and Technology (KAIST), Korea Institute for Advanced Study (KIAS), Gwangju Institute of Science & Technology (GIST), Korea Atomic Energy Research Institute (KAERI), Korea Institute of Nuclear Safety (KINS) remain directly under MOST to support or carry out specific duties relative to the Ministry's mandate.

Ministry of Commerce Industry and Energy has helped in establishing industries for the development and utilization of nanotechnology. It also supports near- and midterm R&D activities for nanotechnology with focus on commercialization. Ministry of Information & Communication main R&D program focuses on NT, BT and IT and it supports IT related nanotechnologies. Ministry of Health and Welfare is primarily engaged in the field of Nano-biotechnology. Other ministry such as Ministry of Employment and Labor (MOEL) and Ministry of Environment (MOE) are involved in standardization and risk management activities regarding nanotechnology. In 2008, MOST and MOE was merged to form the Ministry of Education, Science and Technology (MEST) and MOCIE and MIC were merged to form Ministry of Knowledge Economy (MKE). This consolidation was done to reduce the number of ministries and repetition of mandates within them.

Korea has the following strengths in its approach to nanotechnology: – (1) Coordination between government departments. It launched its Nanotechnology Comprehensive Development Project (NTCDP) in 2001 which was funded by nine different government ministries; (2) University-Industry Linkage: Connected R&D projects between industry, university and other institute has evolved into well coordinated programmes with government support for rapid commercialization; (3) Infrastructure development for public and private actors - developed National Nanotechnology Centres to build the infrastructure needed by the nanotechnology community. South Korean universities are establishing new departments of nanotechnology to meet the needs of industry. (4) Long term commitments: National Program for Tera-level Nano devices and Centre for Nanostructured Material Technology were set up as ten-year long collaborative programmes between industry, universities and government focused on high tech development.

Figure 2.9 highlights the roadmap for nanotechnology development undertaken by South Korea.

Figure 2.9: **Timeline view of nanotechnology development in South Korea**



Source: Constructed from annual reports of the Ministry of Science and Technology S. Korea

Figure 2.9 highlights the well articulated roadmap undertaken by Korea supported by the governance structure). From 2008 onwards one finds more aggressive focus on translational research. Nanotechnology clusters are being created within existing ICT and automotive clusters.

Box 2.3: **Daedeok Innovation Cluster in South Korea**

Daedeok is considered as one of the key centres of South Korea's high-technology R&D and venture businesses since the late 1990s. Daedeok cluster has been developed as a Science town. There has been strategic investment in this cluster in order to create research expertise, capacity, infrastructure and business for more than three decades. In 2005, a special law for fostering Daedeok R&D special district was passed. The innovation cluster has a Daedeok Research Park, Daedeok Techno valley, Daejon Regional Industrial Parks and National Defence Research Centre. It contains six different kinds of institution working towards innovation and commercialization of technologies including nanotechnology- (1) Universities (Chungnam University, Pai Chai University, Hannam University); (2) Research institutes (Korea Advanced Institute of Science and Technology- Nanotechnology Research Facility, Korea Institute of Machinery and Materials- specialized in Nano-imprinting technology, Korea Research Institute of Standards and Science; (3) Supporting government institutions (Korean Intellectual Property Office and the Small and Medium Business Administration, National Nano Fab Center); (4) Corporate research institutes/venture corporations (Hanwha Chemical Research, Sun Biotech, Samsung Electronics, ABC Nanotech, LG Chemical Ltd). The goal is to develop skill, knowledge, and business ideas flow among the policy makers, researchers and businessmen.

Daedeok is extensively involved in various areas of advanced research: new materials, telecommunications, biotechnology, water, nuclear and hydro power, nuclear fusion, design, measurement technologies, mechanical engineering, fuel cells, aeronautics, robotics, new drugs and environmental technologies.

Nanotechnology centre is strategically situated within this cluster to strengthen competitiveness of the above areas.

Source: Authors research based on South Korean policy documents

Table 2.6: **Lessons from South Korea's nanotechnology development**

Advance planning	• Nanotechnology programs and actions are being set at the highest political/governance structure of the country. • Since the mid 1990s, a growing number of state funded projects in nanotechnology were initiated. • In 1999, the S.Korean government started 21^{st} century frontier R&D Program. Nanotechnology identified as an important area of research. • S.Korea subsidized the research on Tera Level Nanodevices and Nano-structured Material Technology. • Korean National Nanotechnology Initiative (KNNI) helped to coordinate R&D activities that were split up across a multitude of projects, state universities and business. It also helped in creating a strategic roadmap for development.
Focused activities	• Nanotechnology was given funding priority after the launch of KNNI in 2001. • Nanotechnology development plan prepared by the government. • Not only institutional but legal guidance/ support for nanotechnology (Action plan for nanotechnology development in 2003 and Presidential Enforcement Decree for the Nanotechnology Development and Promotion Act).
Selection and concentration	• Key areas selected: Information Technology, Biotechnology, Environmental Technology, New Materials, Nanotechnology, Space Technology and Atomic Energy. • Role of University in promoting research. • Role of Government Research Institutes: Targeted technology development with whole range of R&D involved. • Role of Government: Catalytic, less direct intervention, collaborative (both chaebol)[9], Small and Medium Enterprises and Government Research Institutes), Cluster approach.
Target setting	• Intermediate and long-term goals. • Stimulation of R&D activities and drastic increase in R&D budget. • Increased basic research and introduction of measures for commercialization within a foreseeable timeframe.
Catch-up strategy	• Government- led mobilization of strategic resources for achieving development goals. • Governmental support for the growth of big business. • Fostering future growth engine. • Rapid market expansion and selective industrial promotion.

[9] Chaebols are family controlled corporate groups. They are the mainstay of South Korean competiveness in the global economy.

South Korea's involvement in nanotechnology, a priority area identified by them for moving ahead in high technologies has led to some significant outcomes. Many of their nanotechnology applications target advanced ICT for example: carbon nanotubes developed as emitters for FED (Field Emission Display) by Samsung and LG Electronics; cantilever type data storage system by LG and Samsung; four Giga NAND flash memory (70nm process applied), Tera bit level flash memory device by Samsung; Nano carbon ball by LG Life Science, ten times higher capability of removing odor than charcoal being applied for appliances for storing foods such as refrigerators.

2.6 Nanotechnology in Developing Economies of Asia

Japan, South Korea, China and India are the major countries in Asia in terms of scientific investment and capacity to undertake scientific research in different areas of science and technology. It is also important to observe nanotechnology development and strategy in other Asian economies that do not have the elaborate scientific infrastructure like the big four Asian countries. ASEAN countries and some other countries in Asia that have undertaken novel strategies are examined.

Thailand established in 2004 a National Nanotechnology Center (NANOTEC) which focuses on three areas: nano coatings (for applications in anti-bacterial and water-repellent textiles, water purification and food packaging); nano-encapsulation (drug delivery systems), and nano-devices (photovoltaics and electronic 'noises'). Nanotechnology is promoted as an entrepreneurship model; providing infrastructure and seed capital support to startups for enabling them to develop nanotechnology based applications that have high socio-economic relevance — for sustainable agriculture where half of the labour force is involved and textiles where it has global presence. NANOTECH has strong thrust on collaboration with academia and industry including foreign firms. Among its partnership is with an Australian company to develop nano-nutrients to increase growth rate and final size of plants. Figure 2.10 highlights key attributes of nanotechnology development in ASEAN countries.

Figure 2.10: **Nanotechnology development strategies of ASEAN countries**

ASEAN COUNTRIES

Thailand

Strong thrust on agricultural productivity and other end user applications (Textile).

Philippines

Nanotechnology applications to accelerate the scientific agro-industrial and economic development of the country.

Indonesia

Strong focus on industrial needs. PPP model with increased private actors' participation.

Malaysia

Basic research to support applications in Materials and Manufacturing, Medicine, Health, and ICT.

Sri Lanka Institute of Nanotechnology (SLINTEC) encourages participatory mode for application development with industry taking the center stage in formulating roadmap i.e. sectoral intervention, etc. One of the successful outcomes of SLINTEC involvement is in their Tyre industry. It has made their tyres (a key industry in Sri Lanka) more efficient through nano intervention. Iran also made an early commitment in nanotechnology. Research activity as visible through research papers shows Iran as the 10th most active publishing in this field. Iran has adopted its own nanotechnology programmes with a specific focus on agricultural applications. The Iranian Agricultural ministry is supporting a consortium of 35 laboratories working on a project to expand the use of nanotechnology in agro sector and food industry. The ministry is also planning to hold training programs to develop specialized human resources in the field. They have already produced their first commercial nanotechnology product Nanocid, an antibacterial product which has potential applications in the food industry. The product has also widespread applications in the production of various kinds of detergents, paints, ceramics, air conditioning systems, vacuum cleaners, home appliances, shoes and garments.

Taiwan undertook a novel initiative to regulate nanotechnology. It launched Nanomark certification system to regulate nanotech products. It established Laboratory for Nanoproducts Testing and Measurement from 2006 and officially registered it as NanoMark Laboratory in 2007. The laboratory under the guidance of TAF (Taiwan Accreditation Foundation) meets the ISO 17025 standards for testing laboratories. The laboratory endeavors to accelerate the industrialization of nanotechnology and follows the industrial policies of the Ministry of Economic Affairs. Besides, it does the initial product quality tests for consumers and provides test reports for industries to apply for NanoMark. The laboratory holds a stand of strict product checks, regulates standards according to functions of products, and encourages sustainable operation of distinguished companies and factories to improve their product images in contest of domestic and international market competency.

2. 7 Key Findings

Nanotechnology is a science intensive interdisciplinary field and calls for highly skilled manpower, sophisticated instruments, cross-disciplinary research focus and functional linkages between academia-industry among others for translating promises into desired economic and/or social outcomes. Capital intensive nature of this technology, technological uncertainty, developing the knowledge base among others has made Government the major stakeholder in nanotechnology development in different countries. Long term plans with significant funding support is visible in countries actively engaged in this field. US by making this as a 'priority' S&T funding area stimulated other countries to engage actively in this field. Along with advanced OECD countries, emerging economies such as China, India, and Iran also started their research programmes in this area from the early stage of development. Thus, wide dispersion of research activity is observed globally in nanotechnology unlike other cutting edge science based technological fields. Among others the early involvement of emerging economies may be due to myriads of sectors where nanotechnology can make significant economic and/or social impact including providing solutions to issues of pressing developmental concerns.

Nanotechnology development requires a participatory approach with the involvement of all stakeholders who influence the technology development. Governance calls for strong linkages between decision making, planning and execution. One of the key issues in nanotechnology governance is regulation and risk mitigation which can lead to responsible technological development (address economic and social welfare without any adverse implications). Regulation which includes risk governance becomes one of the central issues as this technology has applications in diverse sectors which range from human health, food to high technology products/processes. One of the major concerns is uncertainty about the effects/potential impacts of this technology. Governance of nanotechnologies involves planning, funding prioritizing and facilitating the creation of knowledge base, developing research and innovation systems, creating supporting institutions and framework for technology regulation, skill development, IPR, risk and standards, etc. It also involves creating institutions for developing interfaces between upstream and downstream activities.

Coordinated international efforts are visible in standard development. ISO has created a specific technical committee TC 229 to cover different aspects of standardisation. Almost all the countries actively engaged in nanotechnology research are members of this committee. Countries have created their own standards and some of them are adopted by TC 229. Nanotechnology applications cover different sectors which have their own rules, regulations and acceptable norms. ISO TC 229 has complex linkages with other technical committee standards in different sectors. European Union is developing their directives for regulation and standardisation. These will have important bearing in the development of international standards.

Risk governance has been approached in different ways by countries — ranging from enforcement to participatory approaches. A common approach is to cover within their overall nanotechnology action plan, strategy for mitigating risk concerns. A visible strategy is towards strengthening sectoral regulations and legal provisions to accommodate perceived/visible nanotechnology risk concerns. In some of the countries, specialized institutions have been created for risk research. The study observes various governance approaches with government acting as the major stakeholder in all the countries.

Two distinct models can be discerned from examination of nanotechnology developed in some countries actively involved in this field. Countries with advanced scientific capacity and highly efficient innovation ecosystem are working in the different domains of nanotechnology; applying nanotechnology to enhance competitiveness in different manufacturing sectors. Emerging countries such as BRICS countries are also following this approach to some extent. On the other hand countries such as Sri Lanka, ASEAN countries with more constrained resources/scientific diversity are focusing on end user applications. It is important to learn from these countries also as they have well directed and targeted approach.

3. India's Progress in Nanotechnology: Reflections in Last Ten Years

3.1. Nanotechnology Initiatives in India: Capacity Creation

"We missed the semiconductor revolution in the early 1950s. We had just gained independence. But with nanoscience and technology, we can certainly be on an equal footing with the rest of the world"

Prof CNR Rao, 2006
Chairman of Scientific Advisory Board to PM

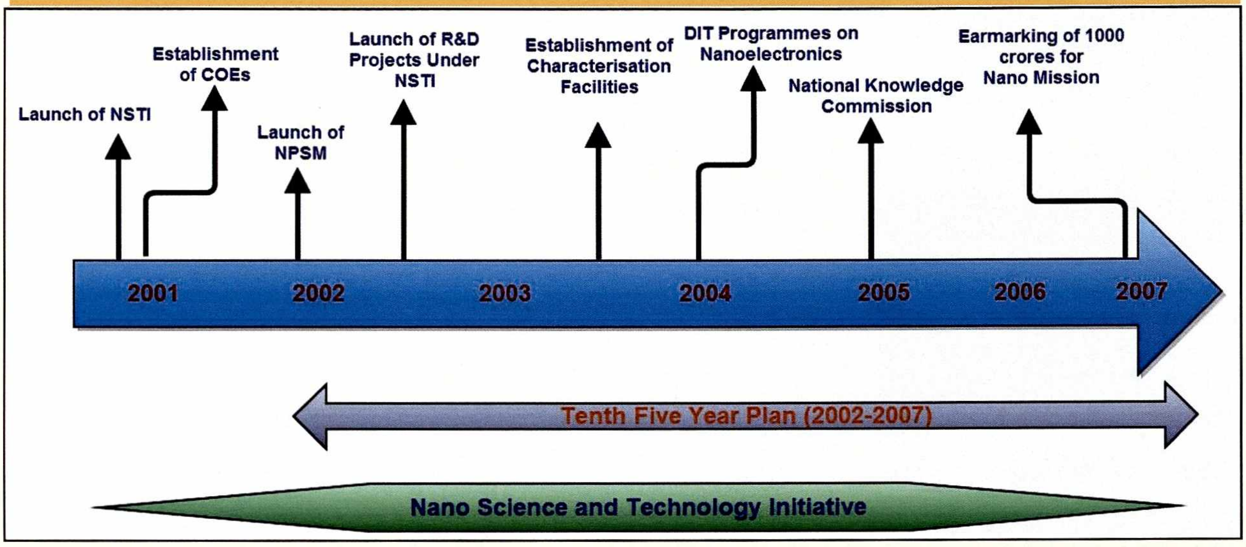
The Indian nanotechnology initiative is a multi-agency effort and has strong similarity with US multi-agency model. However, unlike US and strategy of some other countries, there is no broad program that overlays program of different agencies. The key agencies that have undertaken major initiatives for capacity creation are the Department of Science and Technology (DST) and Department of Information Technology (DIT). Other agencies showing major involvement are the Department of Biotechnology (DBT), Council of Scientific and Industrial Research (CSIR), Ministry of New and Renewable Energy (MNRE), Ministry of Health and Family Welfare (MoHWF), Indian Council of Agricultural Research (ICAR), Indian Space Research Organization (ISRO), Department of Atomic Energy (DAE), and Defense Research and Development Organization (DRDO).

Nanotechnology as a distinct area of government research started with NSTI (Nano Science and Technology Initiative) in the X plan period (2002-2007) with an allocation of rupees 60 crores (approx. USD 12 million).[10] NSTI was initiated and implemented by the DST. NSTI helped in establishing units for developing research excellence in nanoscience, centers for nanotechnology each aimed at application development and two national instrumentation/characterization facilities. In all, fourteen national institutions, including seven IITs and ten universities have been supported

[10] Discussion with DST-Nano Mission

under the NSTI. The other major program that complimented the nanotechnology initiatives was the National Program for Smart Materials (NPSM) launched in 2002. Figure 3.1 exhibits the major initiatives during the X plan period.

Figure 3.1: **Major initiatives in nanotechnology (2001-2007)**



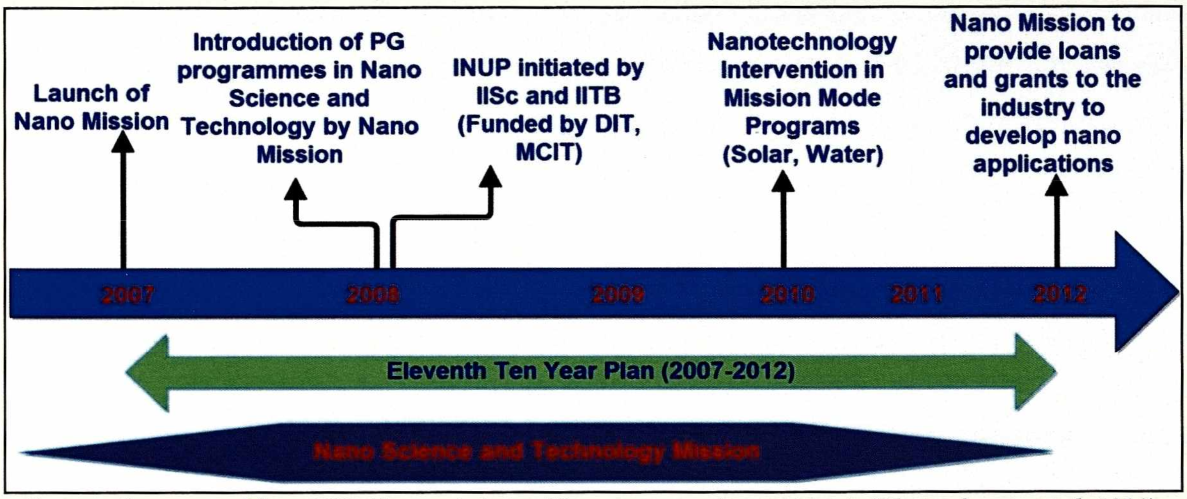
Source: Constructed from DST (dst.gov.in/scientific-programme/ser-nsti.htm), (Bhattacharya, et al. 2011)

In the eleventh plan period (2007-2012) more ambitious programmes and targets were set. Different domains where nanotechnology can play a key role in enhancing the sector competitiveness started receiving attention. This led to nanotechnology emerging as a multi-agency effort/programme. Figure 3.2 exhibits the major initiatives undertaken during the eleventh plan period.

Among the major step taken was the launching of 'Nano Mission' by the DST. This was a follow up of the NSTI programme. Nano Mission was allocated Rs 1000 crores (250 million USD)[11]. This programme strengthened the initiatives and programs undertaken in NSTI; provided liberal support for promoting basic research by funding individual scientist and creating centers of excellence (COE), establishing a chain of shared facilities across the country for enabling use of expensive and sophisticated equipments, promoting application oriented R&D projects, fostering public-private partnership, international collaboration and providing education and training to researchers and professionals. Till 2011, about 260 R&D projects were supported under these two programmes.

[11] The actual allotment was Rs 730 crores and total expenditure of Nano Mission has been Rs 507.55 crores.

Figure 3.2: **Major initiatives in nanotechnology (2007-2012)**



Source: Constructed from DST (dst.gov.in/scientific-programme/ser-nsti.htm), (Bhattacharya, et al. 2011), Discussions with DST-Nano Mission, Department of Information Technology

Different scientific departments/agencies also have their own allocations for nanoscience and technology programs/activities. They have focused on key areas: for example DIT (nanoelectronics), DBT (nano-medicine), CSIR (energy, metrology, and nano-medicine/pharmaceutical), ARCI (water, textile, and smart materials), NIPER (nano-pharmaceutical, toxicology). Table 3.1 shows the expenditure by various stakeholders between the years 2001-2012.

Table 3.1: **Expenditure on nanotechnology R&D by various stakeholders (2001-2012)**

Stakeholders	R&D Expenditure in Nanoscience and Technology (in Rupees Crores)
Department of Science and Technology	567.55 (NSTI 60;Nano Mission 507.55)
Department of Information Technology	326.63
Central Manufacturing Technology Institute	67.23
Indian Council of Agricultural Research	10.18
Council of Scientific and Industrial Research	0.78

Note: 100 crores ≈ 27 million USD; The total reported expenditure is Rs 973.37 crores (263 million USD). Besides this other agencies including industries have also made expenditure for which figures are not available at this stage.

Developing international collaboration is part of the programme agenda of the Nano Mission. Among some of the tangible international collaborative outcomes is the joint EU-India Nanotechnology Research fund worth €10 million created in 2007. Efforts are on to encourage interaction between scientist in the countries and regions to develop electronic archive of nanoscience and nanotechnology publication between EU, China, India, and Russia through International Cooperation Partner Countries Nano Network (ICPC Nanonet).

India has also initiated bilateral cooperative engagements with Germany, Italy, Taiwan, Brazil and South Africa to fund research on materials, health care, water and energy. It has formed a ministry level committee with China in 2006 on S&T cooperation with joint projects planned in many technologies including nanotechnologies. The IBSA (India-Brazil-South Africa) nanotechnology initiative is a collaborative research and development programme for South-South collaboration on the promotion of nanotechnology for clean water. IBSA identifies three areas of research as high priority: nanofiltration and ultrafiltration membranes; nano-based water purification systems for remote and rural areas; carbon nano gels, nano tubes and nano fibers. India has also entered into bilateral nanotechnology programmes with the European Union, Germany, Italy, Taiwan and the United States. A tangible outcome of foreign collaboration was the creation of a national centre for nanomaterials at ARCI in collaboration with Germany, Japan, Russia, Ukraine and the United States. Nano Mission has also promoted international collaboration to provide advanced research facility. This has been possible through the joint India-Japan and India-Germany Beamline facility. Scholar exchange programme has been initiated through joint India-Canada exchange programme.

3.2 Key Stakeholders Involved in Nanotechnology Development

Nanotechnology has evolved as a multi-agency programme with various scientific agencies providing support for creating capacity and directing application development in key sectors. Bio-medicine primarily drug delivery, water, textiles and nanoelectronics (sensors of varied types, etc) have emerged as key areas where major activity is happening. This has been possible due to the involvement of various stakeholders: multi-agency government involvement, academia, research institutes, private sector and international collaborative network. Some of the key stakeholders are highlighted in this section.

3.2.1. Government- A Key Player

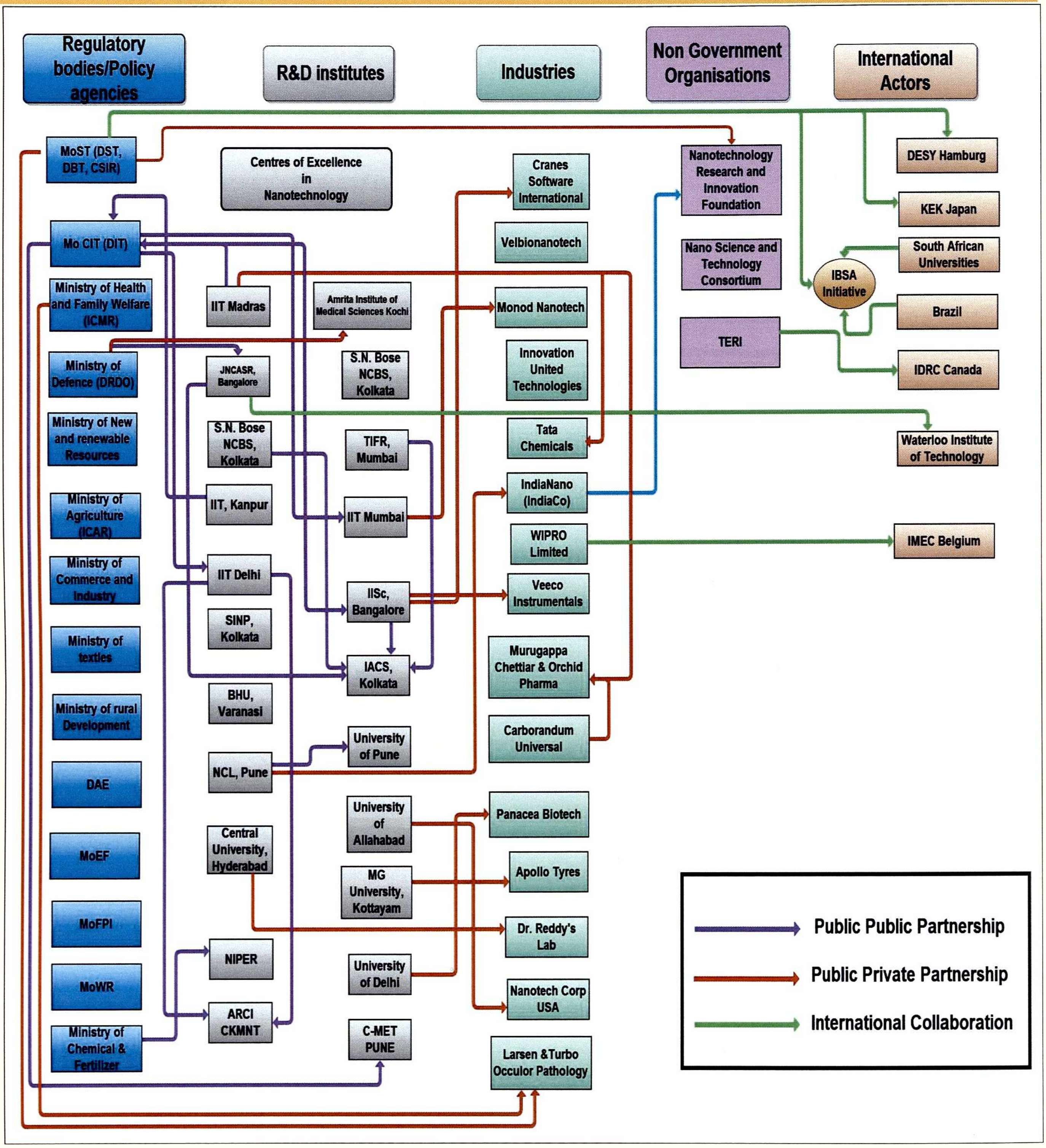
Along with the DST coordinating Nano-Mission and DIT involvement in nanoelectronics, other ministries and organizations such as DBT, CSIR, DRDO have also become important stakeholders in India's nanotechnology development. Motivated by this support, universities, research institutes, and private firms are also emerging as important players in this area.

DST is the key scientific agency which articulated and implemented the Nano Science and Technology Initiative (NSTI) and the ongoing follow up programme the Nano Mission. They are umbrella programmes for creating research and innovation capacity in nanotechnology. Nano Mission is headed by Nano Mission Council which has two advisory groups looking after the technical programs under this mission. First is Nanoscience Advisory Group that focuses primarily on funding basic research and development activities. The other is Nano Application and Technology Advisory Group (NATAG) which tries to promote application and commercialization of basic research by creating links between research institutes and industry.

The various government departments/scientific agencies have linkages with the Nano Mission. They are also articulating and funding their own programmes primarily directing focus more towards sectoral interventions. CSIR, DBT, DIT, DRDO, DAE, ICMR, ICAR and ISRO are among the key stakeholders. DIT initiated nanotechnology development programme especially in capacity building, infrastructure and R&D in nanoelectronics and nanometrology. This programme includes around 24 small and medium R&D projects. DBT has started promoting nano-biotechnology courses in its ongoing curriculum revising exercise to boost application oriented R&D. In addition, research organisations (CSIR, IACS, JNCASR, BARC, DRDO, NIPER, ARCI, C-MET, Agharkar Research Institute) various universities, Centres of Excellence created by DST (under NSTI and Nano Mission) and DIT are involved in nanotechnology research.

At federal level some states such as Karnataka, Andhra Pradesh and Tamil Nadu has shown interest in nanotechnology. The developments in these states include establishment of research institutes; Institute for Nano Science and Technology in Karnataka, ICICI knowledge Park in Hyderabad (Andhra Pradesh), and Nanotechnology Park proposed by Tamil Nadu Government. The Tamil Nadu Technology Development and Promotional Centre supported a nanotechnology conclave in 2008 organized by Confederation of Indian Industry (CII) to promote and exhibit India's capacity in nanotechnology to leading nanotech players. Figure 3.3 shows key bodies involved in nanotechnology development in India.

Figure 3.3: **Key actors/ stakeholders involved in nanotechnology activities in India**



Source: Constructed from Reports and Survey

Nano Bangalore is an annual international conference promoted and supported by the Government of Karnataka. It is emerging as an important forum for students and young researchers academic industry interface and provides opportunity to interact with experts.

3.2.2 Academia

Universities and engineering colleges are adopting nanotechnology in their course curriculum — as separate introductory courses at the degree level, specialised M.Tech programmes (general & sector based) and doctoral programmes. Universities have started research from their internal funds and some have received extramural research grants. Also programme/institutions such as Indian Nanoelectronics User Program (INUP), Inter University Accelerator Centre (IUAC) provides support to academia for nanotechnology research. The section highlights universities that are playing a major role.

3.2.2.1 Indian Institute of Technology

The 'Indian Institutes of Technology (IITs)' are a group of fifteen autonomous engineering and technology-oriented institutes of higher education established and declared as Institutes of National Importance by the Parliament of India. There are eight established IIT's, IIT-Roorkee, IIT-BHU, IIT-Kharagpur, IIT-Bombay, IIT-Madras, IIT-Kanpur, IIT-Delhi, IIT- Guwahati. In addition to eight established IITs, Indian government has opened eight new IIT's. New IIT's are IIT-Ropar, IIT-Bhubaneswar, IIT-Gandhinagar, IIT-Hyderabad, IIT-Patna, IIT-Rajasthan, and IIT-Mandi. IITs mainly the established ones are actively involved in nanotechnology research. Some of them are Centre of Excellence in this field and have specialized units for nanotechnology research. IITs are also offering courses at the M.Tech level and different departments have PhD scholars pursuing doctoral research in this area.

3.2.2.2 Indian Institute of Science (IISc)

IISc has grown to become India's premier centre for research and postgraduate education in science and engineering. It has over the years established several new areas of research, many of them first time in India. IISc made an early commitment in nanotechnology research and through funding support from DIT established the 'centre of excellence' in nanoelectronics. IISc 'centre of excellence' in nanoelectronics focuses on research and education in the areas of nano-scale electronics, devices, technologies, materials, micro and nano-electromechanical systems, bio-electronic interfaces, and integrated small-scale systems. The centre has nanofabrication facility. The center runs a multidisciplinary research program which is funded by the DIT (MCIT), under a collaborative project between IISc and IIT- Bombay. INUP is also a component of this programme which provides academic support to user community in nanoelectronics.

Some of the key research areas of focus in IISc are nano CMOS transistors, non-silicon based transistor, normal memory architectures, high-KGate dielectrics, soft lithography, optical MEMS, acoustic sensors, inertial sensors, CMOS-MEMS integration, and chemical/gas sensors.

3.2.3 Research Organizations

Public funded research organizations have been the major stakeholder in developing knowledge capacity in the country. CSIR, ICAR, DRDO, ISRO, ARCI, IACS, JNCASR, NIPER, BARC are playing a major role in nanotechnology research. Activity of some of the major research institutes are highlighted in this section.

3.2.3.1 Council of Scientific and Industrial Research (CSIR)

CSIR, established in 1942, is an autonomous R&D organisation comprising of 37 national laboratories, four units and 39 outreach centers spread across the nation.[12] It undertakes cutting edge research in wide range of scientific disciplines and has built up a base of scientific and technical knowledge visible through its extensive publication in different research fields and patent portfolio. It is undertaking research in different domains of nanotechnology but essentially focusing in bio-medical, clean energy, water, sensors, and new materials. It is the central agency for standard development for nanomaterials.

Box 3.1: **Nanotechnology Activity in CSIR Laboratories**

National Physical Laboratory (NPL): National Metrology Institute of India has designated responsibility to NPL to formulate nanotechnology standards. It has been contributing to this activity as (i) member ISO-TC-229, (ii) Asia Pacific metrological programme membership (iii) Bureau international des Poids et Mesures sponsored activities, (iv) at the national level – coordinating with BIS for developing national level standards and DST nanotechnology regulatory framework taskforce. DIT has created national facility for nano-metrology and standard development. NPL has identified three areas for developing standards in nanotechnology: (1) Standardization of magnetism in magnetic nanoparticles (2) Standardization of optical emission from quantum dots, and (3) Process standardization.

[12] CSIR, (2011). Annual report 2010-2011. CSIR: New Delhi.

NPL is also involved in nanotechnology intervention in renewable energy primarily solar cells as a major research focus.

Central Salt and Marine Chemicals Research Institute: Nano enabled electrochemical sensors, polymers. Key focus area is in water in which nanotechnology based interventions are visible.

Central Electronics Engineering Research Institute (CEERI): Microelectronic devices and circuits, development of new materials, technology and manufacturing equipment

Central Scientific Instruments Organization (CSIO): A new approach to health diagnosis has been developed by the CSIO. Theoretical simulation and design parameters for a micro-diagnostic kit using nanosized biosensors are based on highly selective and specific biosensors and receptors like antibodies, antigens and DNA, which enable early and precise diagnosis of various diseases. The diagnostic kit 'Bio-MEMS' (microelectro-mechanical-system) has the size of about 1 cm^2, costs around INR 30 (less than 1 dollar) per piece and is easy to apply. Testing time is rapid and only requires a tiny amount of blood. This novel diagnostic tool can also find application in the detection of other diseases and pollutants in the environment, including water and food

Central Glass and Ceramics Research Institute (CGCRI): Novel electrode materials for high power lithium-ion battery technology for applications in electric vehicles (EV), batteries must sustain a high rate current withdrawal and have good cycle life. CGCRI developed nanocrystalline LiNi Mn O - S 0.4 1.6 4d d which has high structural stability. This promising research can help develop high power batteries suitable for EV applications.

National Metallurgical Laboratory (NML): Biphasic calcium phosphate nano-bioceramic for dental and orthopaedic applications: The technology has been transferred to EUCARE Pharmaceuticals Pvt Ltd. Chennai for commercialization. The product is being marketed as Sybograph.

Institute of Minerals and Materials Technology (IMMT): Prepared anti-reflective, nanometric anatase grade titanium dioxide films employing pulse laser ablation based deposition method. Prepared silver nanoparticles by using two types of silver salt and silver complexes. Ultra Violet/Visible spectrophotometric studies have been carried out for the absorbance study of the silver nano sol at different time intervals. The particles show absorbance in the range of 420 - 450nm.

National Institute of Science Technology and Development Studies (NISTADS): Examines various issues related to nanotechnology research and innovation.

Nanotechnology projects under New Millennium Indian Technology Leadership Initiative (NMTILI) Projects in CSIR

Three nanotechnology projects are being undertaken under the ongoing NMITLI projects: Development of nanoparticle based formulation for oral delivery of insulin, Pharmacological and genomic investigations on Ashwagandha plant, and conversion of cellulose and hemicellulose into sugars and ethanol-expansion.

3.2.3.2 Defence Research and Development Organization (DRDO)

DRDO works under the Ministry of Defence. DRDO is working in various areas of nanotechnology especially on futuristic weapon system capabilities which they intend to enhance through nanotechnology such as: sensors, actuators and displays, advanced materials and composites for aerospace systems, micro vehicles as military drones, smart textiles. It is also putting its expertise in addressing issues of pressing concerns. Under this initiative it has developed diagnostic tools for tuberculosis and typhoid.

3.2.3.3 Jawaharlal Nehru Centre for Advanced Scientific Research (JNCASR)

JNCASR is a multidisciplinary research institute funded by the DST. Nanotechnology is an active area of research of this institute. In this area it primarily undertakes research in the field of synthesis and characterization of a variety of nano objects such as tubes, wires and particles of different materials, their chemical modification and organization as well as thin films and powders of transition metal oxides showing interesting physical properties. Theoretical modeling of nanosystems has also been taken up in order to understand the underlying mechanisms, giving such interesting properties. Among its recent activities is the development of inorganic nanotubes and nanowires and research on issues concerning the way transport occurs in mesoscopic quantum systems.

In order to develop the research community in this area, the institute is involved in many academic activities such as development of courses in nanoscience, discussion meetings and symposia. Model M.Tech curriculum has been developed by this institute towards setting a standard for teaching nanoscience at post-graduate level in the country. It provides postdoctoral fellowships in nanoscience which is funded by DST. The institute has set up instrumentation facility supported and jointly operated by Veeco India Nanotechnology Laboratory. The instrumentation facility is strengthened by Nano Mission. A recent addition is the highly sophisticated TITAN microscope funded under this programme.

3.2.3.4 Bhabha Atomic Research Centre (BARC)

BARC is applying nanotechnology in the development of advanced heavy water reactor (AHWR) and the compact high temperature reactor (HTR) and the non-power applications of nuclear energy. It has developed a variety of nano-sensors and accentuators, and application-specific integrated circuits. The centre is working further in designing and manufacturing nano-sized mechanical devices, employing fabrication technology of nano-metre scale.

3.2.3.5 The Indian Association for the Cultivation of Science (IACS)

IACS is an autonomous institute which is controlled by a General Body and Governing Council. It receives fund from the DST, Government of West Bengal, many public agencies (CSIR, DAE), private companies as well as foreign sources NSF, UNDP, Japan, European Union, Sweden etc. The main mission of this institute is to undertake fundamental research in natural sciences and interdisciplinary streams. Development, synthesis and study of the various properties of nanostructural materials are some of the major activities of this institute in nanotechnology. The major research work is on the size and morphology dependent optical properties of nanomaterials, colloidal semiconductor nanocrystals and core-shell structure. It has also started looking at energy transfer in quantum dots; size induced structural phase transition, electrical properties of nanostructred conjugated polymers and polymer electrolyte nanocomposite. Another area of active nanotechnology research of this institute is towards the development of amorphous and nano-crystalline silicon for solar energy devices.

3.2.3.6 National Institute of Pharmaceuticals Education and Research (NIPER)

NIPER is actively involved in bio-medical research and application. It is undertaking research and nanotechnology for targeted drug delivery and nanomedicines. It has a dedicated Centre for pharmaceutical nanotechnology. A key role played by this institute is towards formulating guidelines for nanotechnology-based drugs.

3.2.3.7 International Advanced Research Centre for Powder Metallurgy and New Materials (ARCI)

ARCI (an autonomous research centre of DST) has a Centre for Nanomaterials that concentrates on the development of technologies for production of nanopowders and also explore their utilization for applications which cater to either a large Indian market or a market unique to India. The centre especially focuses on vast array of synthesis, processing and characterization facilities, but also in application development in the areas of nanosilver for drinking water disinfection, nano-ZnO for electrical varistors, nano alumina-based cutting tool materials and nanotungsten carbide as non-noble catalyst in PEM fuel cell electrodes. New projects related to functional textile finishes, utilization of aerogels for thermal insulation applications, synthesis of inorganic fullerenes and establishment of pulse electrodeposition to make nanostructured coatings and catalysts have also been recently taken up. It has an outreach centre CKMNT which is involved in disseminating research trends and creating awareness of nanotechnology in the country.

3.2.3.8 Centre for Materials for Electronics Technology C-MET

C-MET functions as an autonomous scientific society under DIT (MCIT), Govt. of India. One of their main activities is in the development of new analytical methods for specific problems especially in areas where regulated or standardized processes do not yet exist. Nanoelectronics have been identified as one of the key areas of research. C-MET has done promising research in this domain and have developed technologies that can have wide applications. Some of the promising technologies include processing of wavelength specific optical cut-off filters (from yellow to red) through nanocomposite technology, nano-sized Ag and gold particle for photonics, quantum dots of CdS, CdSe, PbSe and InP for light emission properties in polymers, nano-sized ruthenium oxide for supercapacitor, and organically capped Ag nano-powder for semiconductors. C-MET has developed few catalysts like mixed metal chalcogenides nanotubes. The nanosize ZnO (17-50nm) have been synthesized and used for sensors (CH4, CO etc) applications. Research is undergoing for production of nanotechnology based raw materials used in various applications like efficient batteries, photocatalysis, sensors, etc, and production of cheap hydrogen from H_2S and water.

3.2.3.9 Inter University Accelerator Center (IUAC)

IUAC is an autonomous research institute of the University Grant Commission, New Delhi. The Centre has dual responsibilities of facilitating research for a large user community as well conducting their own research. It works in diverse research areas covering applied physics and interdisciplinary areas. This centre is now actively working in nanotechnology research and providing access to researchers in different universities for accessing their facilities. Some of the important areas of nanotechnology research includes: silver fullerene nanocomposite thin films for applications in optical devices; nanocrystalline thin films; embedded nanoparticles; metal nanoparticles dispersed polymeric films; nanocomposite nanofibers.

3.2.3.10 Agharkar Research Institute

Agharkar Research Institute (ARI) is an autonomous, grant-in-aid research institute of the DST, Government of India. Centre for Nanobiosciences was established in 2007 for conducting research in diverse areas such as nanomaterials synthesis and characterization, to developing products and processes for the improvement of human health, agriculture, environment, etc. Its research activities cover diverse areas of nanobioscience. For example, it has developed eco-friendly methods of synthesizing metal and semiconductor metal sulfide nanoparticles using yeasts, ordered assembly of nanoparticles on bacterial surface layer protein templates and fabrication of a functional electronic device, viz. a diode using microbially synthesized semiconductor nanoparticles. It has also worked on inventions on biostabilizing submicronic particles, developed design and fabrication of an apparatus for separating nanoparticles and discovery that biostabilized silver nanoparticles possess potent antimicrobial activity and are safe for human application. A new drug formulation has been developed based on nanocrystalline silver gel for the treatment of burns and wounds and has been approved by the Drug Controller General of India (DCGI) after completing multi-centre clinical trials. This drug has been licensed to a pharmaceutical firm.

3.2.4 Industry

All major industrial associations in the country i.e. 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 involved in the promotion of nanotechnology. ASSOCHAM has a Nanotech Governing Council; in 2007 it organized the 5th Global knowledge millennium summit — B2B in biotechnology and nanotechnology focusing on bio-nanomedicine, nano electronics and nano agri-biotechnology. FICCI, in partnership with DST, has organized India R&D conferences on 'Nanotechnology- Science of the Future' in 2008, in order to sensitize the industry, R&D institutes and investors on various issues related to this technology.

CII started its own nanotechnology initiative in 2002 to create a supporting environment for industry through knowledge exchange missions, awareness programmes, workshops, market research and other range of services. Since then it is working with Government of India on bilateral international initiatives on knowledge sharing and technology linkages. Under this initiative CII in partnership with the DST organized Nanotechnology Conclaves annually starting from 2006 to facilitate collaborations between industry and institutes. It has also put together a ten-point action plan to address commercialization of nanotechnology. The action plan includes awareness creation, training and skills development, technology facilitation and networking and initiating collaborative projects. It is facilitating bilateral industrial research projects in nanotechnology.

CII has done preparatory work on regulatory issues. It has urged the Government to establish a strong network of infrastructure facility to support industry, development of a suitable human resource base in this emerging technology, development of standards and procedures and harmonising with international standards. More importantly, the CII has urged the government to set up a dedicated fund for commercialization of nanotechnology products in the form of soft loans, repayable after five years of sales at attractive interest rates. CII has initiated university-industry collaboration for providing industry inputs in the field of research and technology for nanotechnology.

Associations/industrial bodies with sectoral focus have also started taking interest in this field. Among them sectoral associations in automotive namely the 'Society for Indian Automobile Manufacturers' (SIAM), and 'Automotive Component Manufacturers Association' (ACMA) has shown keen involvement. Various industry-academia forums have been held by them.

A number of private sector actors have started investing in nanotechnology activities. It is estimated that industries have invested around 1000 crores (approximately 250 million USD) so far. Some big companies such as Tata Steel, Mahindra & Mahindra, Panacea Biotech, Nicholas Piramal, and Intel have designed major programs for nanotechnology development. For example, Panacea Biotech, and Reliance Life Sciences are developing nanotechnology based drug delivery systems. Reliance is also focusing on preparation on nano enabled fibers for sutures, scaffolds etc. The Tata Chemicals

Innovation Centre created in mid 2004 has a major focus on developing nanotechnology based applications with a strong focus on low cost solutions to existing pressing problems.

Linkages are emerging among public sector R&D and industry. Table 3.2 highlights some of the major public-private partnerships developing in this area.

Table 3.2: **Joint institution-industry linked projects**

Institute	Industry	Areas of Collaboration
Nano Functional Materials Centre, IIT Madras	Murugappa Chettiar, Orchid Pharma, and Carbrandum Universal	Cost effective method for production of oxide ceramic powders of nano size. Consolidation and sintering of nanocrystalline oxide powders for production of bulk ceramics, nanocrystalline diamond films/coatings on die-inserts and plugs
Nano Technology Centre, University of Hyderabad	Dr. Reddy's Labs	R & D on drug delivery system using nano-carriers
Centre for Interactive and Smart Textiles, IIT Delhi, and ARCI	Resil Chemicals, Pluss Polymer, Purolater India	Investigation of novel methods suitable for integrating novel textile materials (nanofibres); materials to textile substrates
Rubber Nanocomposites, and MG University, Kottayam	Apollo Tyres	Development of novel technologies in tyre engineering based on nanosize fillers
Nanotechnology Application centre , University of Allahabad	Nano Crystal Technology	Development of nano phosphor (applications in solid state lighting, display technology)
Indian Institute of Science	Cranes Software International.	Establishing the Micro Electro Mechanical Systems (MEMS) Research Lab to conducts research in MEMS and develops designs for MEMS-based devices.
Department of Chemistry, University of Delhi	Panacea Biotech	Developed nanoparticles to encapsulate steroidal drugs for delivery to the eye and technology transfer to Panacea Biotech for commercialization.
Jawaharlal Nehru Center for Advanced Scientific Research	Veeco Instruments	Creation of advanced instrumentation such as high end SPM, optical profiler.

Institute	Industry	Areas of Collaboration
Solar Photovoltaics	Amrita and Bharat Electronics	Development and training of young researchers in the area of nanotechnology as applied to thin film, deposition and photovoltaic.
Punjabi University, Guru Govind Singh Indraprashta University	Insta Power, Delhi	Preparation of silicon sheets for solar cell applications
CSIR-NPL, CSIR NCL	Moser Baer	Solar photovoltaic , Wind energy

Source: DST; Parliament of India. *http://dst.gov.in/admin_finance/ls_14/un_sq2455%20%20.htm; Author's Own Survey.*

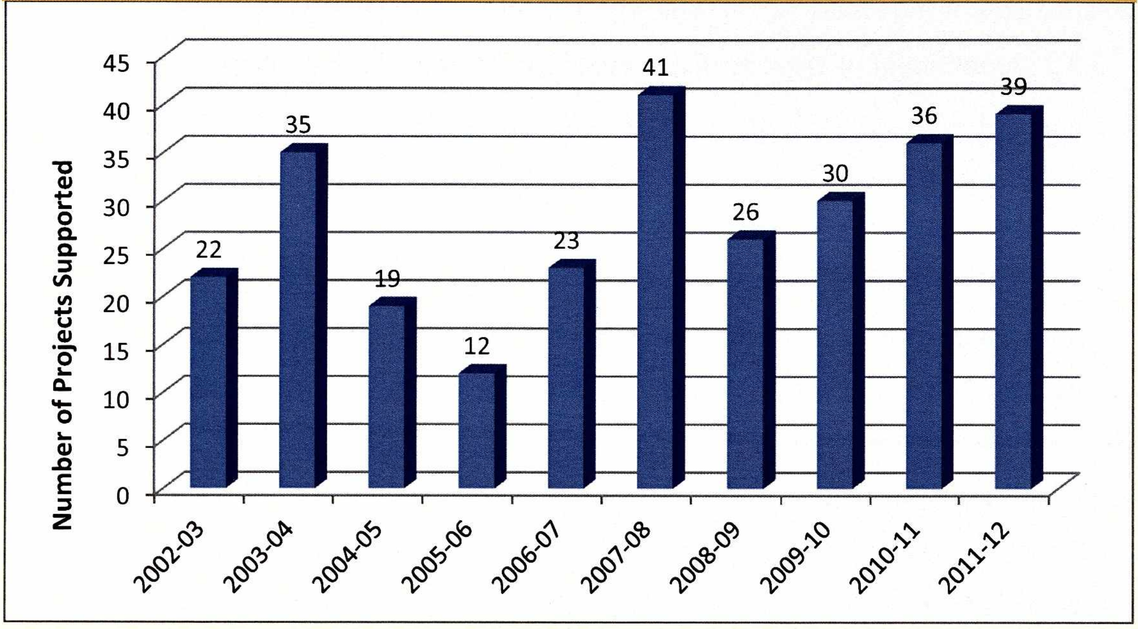
Under the Nano Mission, Nano Applications and Technology Advisory Group (NATAG) has been constituted with the objective to encourage implementation of industry-centric and application-driven projects in the area of nanoscience and technology. NATAG has started supporting Joint Industry-Institution Projects under its Nano Applications and Technology Development Programme (NATDP). It aims to primarily promote nanotechnology-based innovation and pre-commercialization projects by extending financial support for encouraging partnerships between industry and public-funded academic/R&D institutions. So far seven such projects have been funded.

3.3 Major Research Initiatives by Key Agencies

3.3.1 Under DST Coordinated Nanotechnology Mission

DST initiated and implemented the NSTI and Nano Mission programmes. Under these two programmes, different kinds of projects were supported focusing on basic research, to create centers of excellence, advanced instruments and facilities and course development. Figure 3.4 exhibits projects supported in this category under these two programmes, NSTI and the ongoing Nano Mission.

Figure 3.4: **Number of basic science projects supported by the Nano Mission**



Source: http://nanomission.gov.in/ ; Discussion with Nano Mission

Note: The 100 basic science project in the NSTI phase includes 10 projects for establishment of centers. The Figure however excludes projects that were not individual scientist centric research projects.

Till 2012 about 285 individual scientist centric research projects were supported. Individual scientist centric projects support is primarily given for fundamental research in nanotechnology. These projects cover research on various aspects of nanoscale systems aimed at looking into new and improved understanding of the relationship between structure of various nanoscale systems and their properties.

i) Strengthening of Characterization Facilities: As a part of Nano Mission, characterization facilities have been made available to various institutions. Sophisticated equipments such as optical tweezer, nano indentor, transmission electron microscope, atomic force microscope, scanning tunneling microscope, matrix assisted laser desorption time of flight mass spectrometer, microarray spotter, scanner have been established at various locations in the country. In addition, accelerator based research facilities have been established at IIT Kanpur, Allahabad University and Kurukshetra University. JNCASR has strengthened its instrumentation facilities by installing TITAN microscope supported by Nano Mission

ii) Infrastructure Development: Creation of Centre of Excellence. An important initiative of the Nano Mission has been the creation of Centers of Excellence. Since 2011 onwards apart from 39 individual scientist centric projects on basic research, Nano Mission has also supported eight Thematic Units of Excellence project and a project on standardization.[13]

3.3.2 Department of Information Technology Research Initiatives

Department of Information Technology DIT (MCIT) initiated the Nanotechnology Development Programme in 2004. Main focus of this department is in nano-electronics. A varied range of initiatives have been taken in this regard: (a) Creation of Centres of Excellence -- Two Centers of Excellence have been created at IIT-Bombay and IISc focusing on development of nano-systems for healthcare and environmental monitoring, development of organic and biopolymer devices, GaN devices, acoustic sensors, among others. (b) Indian Nanoelectronics User Program(INUP): The above two centers are reaching out to nano-electronic researchers across the country by providing them resource facilities – advanced instruments and peer support. (c) Development of Molecular Beam Epitaxy Cluster Tools for the epitaxial growth (e) Non-silicon based nano fabrication and nanoscale devices. (f) Centre for Nano-Electro-Mechanical Systems (NEMS) created at IIT-Madras for carrying out R&D activities and manpower development in this area. (g) National Facility for Nano Metrology and Standard development at CSIR-National Physical laboratory. (h) Transferred-arc Plasma Generation System at Centre for Materials for Electronics Technology (C-MET Pune) for large scale (Industrial scale) production of nano-sized metals, metal oxides and metal nitrides. (i) A facility for the development of III/V Compound based Quantum Dots for the development of fundamentally new devices for single photon sources and detectors at IISc, Bangalore is being created. (j) A facility for the growth and characterization of single wall carbon nanotubes is being created at Jamia Millia Islamia University, New Delhi. (k) Dip-Pen-Nano based nano-patterning facility has been setup at CSIR-Central Electronics Engineering Research Institute for nanofabrication being used in application such as biosensor arrays, photonics and nano-circuitry. (l) A facility and multidisciplinary expertise has been created for development of bio-nano sensors for healthcare and agriculture application at CSIR- Central Scientific Instrument Organization.

3.3.3 Department of Biotechnology

Department of Biotechnology is also one of the key stakeholders in nanotechnology development in India. It is trying to promote research in nanobiotechnology. In this direction, it has invited project proposals to address various issues in the areas of health, agriculture, food and environment through basic and applied nano biotechnological research interventions. Some of the areas addressed in its projects are: design of new therapeutics and targeted drug delivery vehicles; novel formulations for

[13] nanomission.gov.in/projects/Sanction/pdf/2011-12.pdf

existing drugs to enhance their efficacy; nano carrier systems for siRNAs therapy; diagnostics for early diseases detection and imaging; design and development of smart nanomaterial for bio separation, tissue engineering and other medical applications; sensors for detection of chemicals and pathogens in food and crops, nano carriers system for pesticides and fertilizers, improving the nutritional qualities of food and smart packaging system etc. One of the major areas of focus of DBT is on toxicology studies on nanoparticles.

3.4 Nanotechnology Centers of Excellence in India

Sophisticated instrumentation facilities have been created in major institutes. Novel initiatives have been taken to allow researchers spread across the country to have access to these resources.

As part of its efforts to promote R&D in nanoscience and technology, the Government of India has already established several centres of excellence in various parts of the country, to carry out fundamental studies on nanoscale systems and explore development of technologies for applications like water purification systems, thermo-regulated textiles, nano fillers for tyre applications, nano biosensors, tissue engineering, drug delivery, nano patterning, etc. These centers have been established and funded by the DIT and Nano Mission.

3.4.1 Centers of Excellence Created by Department of Information Technology

Two centers of excellence were established by DIT in IIT Bombay and IISc Bangalore. These centers possess facilities for nano-device fabrication. The two centres collaborate actively with over a dozen leading international semiconductor industries and receive substantial funding from them. For example, at IIT-Bombay, Applied Materials has created a 'Nano-manufacturing laboratory' with equipment for CMOS fabricaton. The equipment involves 8-inch cluster tools for high-k deposition, PVD Endura and Etch Centura with the total cost of donation amounting to approximately US $ 10 Million. There are also applied materials researchers stationed at IIT-Bombay for running, maintenance and research activities involving these tools. IIT-Bombay has also generously funded this project as part of its internal thrust area programme. Overall, at IIT Bombay, Rs 100 crore facility (approx USD 25 Million) is operating currently with active involvement of Government, industry and IIT Bombay. Over 100 users currently use this facility at IIT-Bombay including users from over 15 organizations in India. The external user programme is supported by the 'Indian Nanoelectronics User Programme' (INUP), supported by the MCIT.

3.4.2 Centre's of Excellence Created under Nano Mission

Centre of Excellence (COE) created by DST under Nano Mission are classified into three categories- Unit of Nanotechnology, Centre for Nanotechnology, and Centre for Computational Materials Science. Initially during NSTI period, Nano Mission Council supported few institutions by identifying key researchers engaged in core nanotechnology field and providing them funding. Later on funding was enhanced and more sophisticated and capital intensive equipments were installed in the identified research institutes. The approach was to create specialised centers that has wherewithal to conduct advanced research in nanoscience and technology. This has led to the creation of eleven Units/Core Groups on nanoscience. These centres of excellence contain sophisticated facilities for sharing with other scientists in the region and helps in promoting scientific research on nanoscale systems in a decentralized fashion.

For advancing nanotechnology research in key sectors, seven centers for nanotechnology were created. These centers are (1) Amrita Institute of Medical Science (Implants, tissue engineering, Stem cell research), (2) S.N Bose National Centre for Basic Sciences, Kolkota (Nanoelectro mechanical System NEMS and Microelectro mechanical system MEMS/ nanoproducts), (3) Tata Institute of Fundamental Research (nanoscale phenomena in biological systems and materials), (4) IIT-Bombay (nanoelectronics, polymer nanosensors, nanobiotechnology), (5) IISc, Bangalore (nanodevices, nanocomposites, nanobiosensors), (6) IIT-Kanpur (printable electronics, nanopatterning), (7) Indian Association of Cultivation of Sciences (IACS), Kolkota (photovoltaic and sensor devices). In addition, a thematic unit on Computational Materials Science has also been established at JNCASR, Bangalore. Thematic unit have been developed to focus on specific domains.[14]

Table 3.3: **Thematic units focusing on specific sectors**

IIT Madras, Chennai	Thematic Unit of Excellence on "Water purification using nanotechnology
IACS, Kolkata	Photovoltiac and sensor devices
S.N. Bose National Centre for Basic Sciences, Kolkata	The Thematic Unit of Excellence on Nanodevice Technology
Amrita Institute of Medical Sciences & Research Centre, Kochi	Thematic Unit of Excellence on Tissue Engineering and Medical Bio-Nanotechnology
Jawaharlal Nehru Centre for Advanced Scientific Research (JNCASR), Bangalore	Thematic Unit of Excellence in Nanochemistry Thematic Unit of Excellence on "Computational Materials Science.

[14] Discussions with Nano Mission.

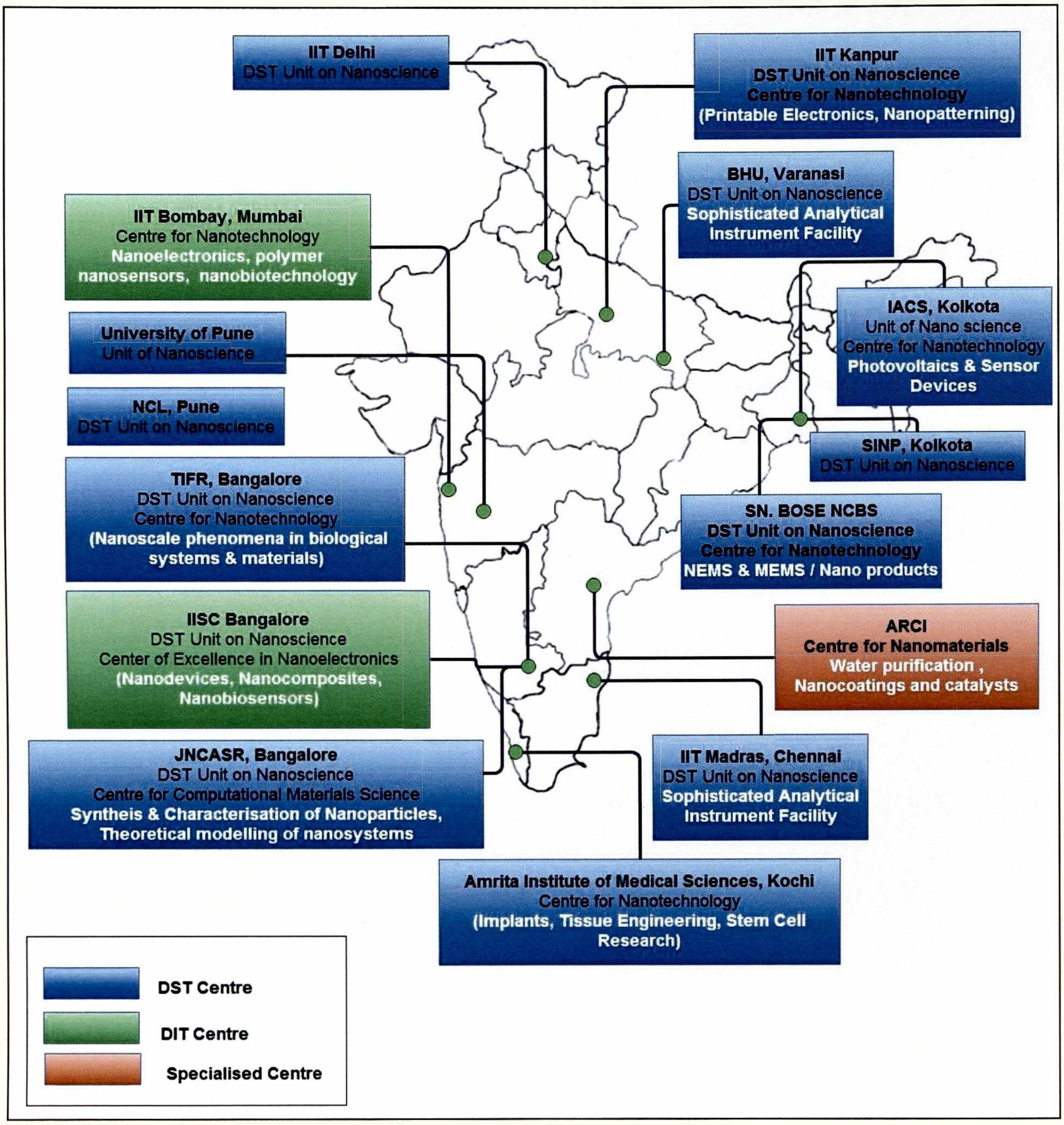
International Advanced Research Centre for Powder Metallurgy and New Materials (ARCI), Hyderabad	Thematic Unit of Excellence on Nanomaterial-based Technologies for Automotive Applications
IIT- Kanpur, Kanpur	Thematic Unit of Excellence on Soft Nanofabrication with applications in Energy, Environment and Bioplatforms
IISc, Bangalore	Thematic Unit of Excellence on "Physics and Technology of Nano Assemblies

Apart from COEs, ARCI also has a Centre for Nanomaterials that concentrates on the development of technologies for production of nanopowders and also explore their utilization for applications which cater to either a large Indian market or a market unique to India. The centre especially focuses on vast array of synthesis, processing and characterization facilities, but also in application development in the areas of nanosilver for drinking water disinfection, nano-ZnO for electrical varistors, nano alumina-based cutting tool materials and nanotungsten carbide as non-noble catalyst in PEM fuel cell electrodes. New projects related to functional textile finishes, utilization of aerogels for thermal insulation applications, synthesis of inorganic fullerenes and establishment of pulse electrodeposition to make nanostructured coatings and catalysts have also been recently taken up.

In addition to these centers an Institute of Nano Science and Technology is being established as a centre of ARCI, Hyderabad, (ii) at JNCASR, Bangalore as a joint centre of JNCASR and IISc and (iii) at IACS, Kolkata.

Figure 3.5 illustrates Centers of Excellence that have been set up in various locations in India.

Figure 3.5: **Nanotechnology centers of excellence in India**



Source: Constructed from Reports

3.5 Human Resource Development

Nanotechnology is highly knowledge intensive and interdisciplinary and demands a highly interdisciplinary research team with multiple skills set. Six fields dominate nanotechnology research 'materials science, multidisciplinary', 'physics, applied', 'chemistry, physical', 'physics, condensed matter', and 'chemistry, multidisciplinary' (Porter A L and Youtie J, 2009). This is an indication of the type of manpower required for this research field. Along with this manpower need to be developed for examining patenting issues which are complex, legal manpower, trained persons for handling sophisticated instruments, etc.

There are diverse viewpoints on the level i.e. at the graduate or at the post-graduate levels nanotechnology is to be a separate degree program. Also there are concerns whether Indian industry is ready to absorb the highly specialized manpower that different institutes wish to create. Some of the initiatives that have been undertaken are highlighted.

3.5.1. Human Resource Development in India

A few academic institutions have taken the lead to introduce nanotechnology courses/programs. Efforts are being made to bring uniformity in course content and develop application oriented focus.

Nanotechnology courses in India include B. Tech, M.Sc., and M.Tech in Nanotechnology, PhD and Integrated PhD. Nano Mission has supported many of the above programmes, both public and private universities based on their performance and grading. To have a proper benchmark, model curriculum for M.Tech course has been developed. B. Tech programmes are visible more in private universities. No reputed public funded university has launched B.Tech programmes. This is in line with the approach of strengthening basic science and engineering capability at the graduate level.

Some of the institutes offering nanotechnology as part of curriculum (elective course), are: JNCASR, IITs, IISc, CSIR-National Physical Laboratory (NPL), CSIR-National Chemical Laboratory (NCL). Nanotechnology as part of curriculum is offered by several institutes: Banaras Hindu University (BHU), Jadavpur University, Sri Venkateshwara University Thirupati, Andhra University, Visakhapatnam, Gulbarga University, Gulbarga, Kuvempu University, Shimoga and Osmania University, Hyderabad.

So far Nano Mission has supported M.Tech in Nanoscience and Nanotechnology in 14 universities and MSc programmes in 3 universities. This includes public as well as private universities. Ministry of Human Resource and Development provides scholarship for students who join M.Tech after qualifying GATE. Nanoscience is not included in the GATE qualification test. To overcome this problem Nano Mission provides fellowship for students in their supported M.Tech institutions.

During the period 2008-2011, 355 M.Tech students and 62 M.Sc students have passed out from the 17 supported institutions[15].

Table 3.4 and Table 3.5 show the post graduate programmes supported by Nano Mission.

Table 3.4: **Nano Mission supported M.Tech programmes**

S.No	Name of the University /Institution	2008-10	2009-11
1	Aligarh Muslim University, Aligarh	13	12
2	Amrita Vishwa Vidya Peetham, Kochi	20	20
3	Anna University, Chennai	14	17
4	GGS Indraprastha University, New Delhi	09	10
5	Guru Jambeshwar University, Hisar	20	20
6	Jadhavpur University, Kolkota	16	16
7	Jawaharlal Nehru Technological University, Hyderabad	-	27
8	Karunya University, Coimbatore	-	17
9	Kurukshetra University,Kurukshetra	-	-
10	Kuvempu University, Shimoga	-	11
11	Periyar Maniammai University, Thanjavore	-	-
12	SASTRA University, Thanjavur	24	26
13	University of Delhi, Delhi	11	-
14	VIT University, Vellore	25	27
	Total	**152**	**203**

Source: Nano Mission

Table 3.5: **Details of students passed out from Nano Mission supported M.Sc. programme**

SNo.	Name of the University/Institution	2008-10	2009-11
1.	Guru Nanak Dev University, Amritsar	15	15
2.	Osmania University, Hyderabad	12	12
3.	Sri Sathya Sai University, Vidyagiri, Anantpur District	08	-
	Total	**35**	**27**

Source: Nano Mission

Some of the universities are providing specialized programmes, for instance M.Tech in Nano Medicine by Amrita Institute of Medical Science. Nano Mission is also supporting Post-doctoral fellowship. JNCASR has now post- doctorate fellows under this programme. It has supported five advanced Schools of Nanoscience and Nanotechnology. Efforts have been on to create national and

[15] Information provided by Nano Mission

overseas post-doctoral fellowships, and chairs in universities. Nanotechnology conferences for example Bangalore Nano has dedicated sessions for young researchers and students.

"Nanotechnology is knocking at our doors. . . Molecular switches and circuits along with nano cell will pave the way for the next generation computers. . . With the emergence of Nanotechnology, there is convergence of nano-bio-info technologies resulting in new devices which has wider applications in structure, electronics, and healthcare and space systems. Potential applications are virtually endless. Progress in nanotechnology is spurred by collaboration among researchers in material science, mechanical engineering, computer science, molecular biology, physics, electrical engineering, chemistry, medicine and aerospace engineering. This is one of the important emerging area which brings synergy in research and development by combining the strengths of the multiple domain knowledge leading to the creation of knowledge society. Our educational institutions and universities should have special purpose missions based on their core competence."

Dr. A P J Abdul Kalam
Former President of India

3.5.2. Developing the Research Community

3.5.2.1 Conferences/Workshops

With the advent of nanotechnology initiative there has been an effort to encourage and facilitate participation of Indian students/young researchers involved in areas of nanoscience and nanotechnology as well as young researchers working in the field. Under the Nano Mission, International Conferences on Nano Science and Technology (ICONSAT) has been conducted since 2003. Table 3.6 shows the ICONSAT conferences that have been held so far.

Table 3.6: **ICONSAT conferences**

Year and location	Organizers	Themes
2003-Kolkata,	Saha Institute of Nuclear Physics, Kolkata	Synthesis, properties and characterization, nano-manipulations and nano-lithography, theoretical studies and applications in biology, catalysis, magnetism, electronics and other areas
2006-New Delhi	IIT-Delhi	Different areas of nanotechnology.
2008-Chennai	Indira Gandhi Centre for Atomic Research, Kalpakkam, Tamil Nadu	Novel synthesis routes, functionality and properties of nanoscale, new application and nanodevice, computational nanoscience and nanobiology
2010-Mumbai	IIT-Madras (Tata Institute of Fundamental Research, Bhabha Atomic Research Centre), Mumbai	Novel synthetic methods, fabrication and devices, functional materials, materials for food and environment, electronics, magnetics and photonics, materials for energy, hybrids, technology for medicine
2012-Hyderabad	ARCI, Hyderabad	Theoretical and computational studies, energy materials, CNTs and graphene, catalysis, nanotoxicology, advances in synthesis and characterization techniques, biotechnology and biomedical applications, magnetics and electronics, thin films, NEMS/MEMS, lithography, structural, surface engineering and tribological applications and nanocomposites

Efforts have been made to make ICONSAT as a platform where scientists, academicians, entrepreneurs, students come and interact on the current developments and future trends in the multidisciplinary area of nanoscience and nanotechnology. Table 7 shows theme focus of different ICONSAT conferences. Industry and student/young researchers' participation has increased over the years. This has been primarily due to focus on these two groups in the later conferences; entrepreneurs provided with exhibit space and also invited for presentations, and students/young researchers provided with liberal funding support to attend the conference, present their work, etc.

Apart from ICONSAT, some other conferences are being held focusing on a particular theme in each addition. Among the two other conferences that are well attended are the Nano Bangalore Conference and International Conference on Advance Nanomaterials and Nanotechnology (ICANN) (held in IIT Guwahati in 2009 and 2011). Nano Bangalore has strong focus on commercialization aspects. It is also important to observe that conferences are being held in different institutions spread across the country.

3.5.2.2 DIT- INUP Projects

DIT has initiated a major project entitled Indian Nanoelectronics User Programme (INUP) at IIT Bombay and IISc Bangalore. The project aims to provide support to different groups in the country working in the area of nanoelectronics. INUP through short, medium and long term projects provides access to the facilities established at the nanoelectronics centers at IISc and IIT Bombay. The major features of the project include — providing a hands-on training in nanoelectronics, assistance in research by enabling execution of work of external users at these centres, collaborating with research teams from other Indian centres to develop joint programs in nanoelectronics, provide a platform to researchers in nano-electronics to come together and benefit from complimentary expertise and conduct regular workshops for a wider dissemination of knowledge in nanoelectronics. In addition, a set of short and medium term projects are being carried out under this program.

3.5.2.3 Centre for Knowledge Management of Nanotechnology (CKMNT)

CKNMT was created in 2009 at ARCI as one of its project centers. The centre intends to encourage exchange and dissemination of advanced technological knowledge and expertise to meet the needs of the nano-researchers, industry, policy makers, financial institutions and venture capitalists. CKMNT has been partially funded by the DST, Govt. of India in a project mode. CKMNT is trying to host a website for publicizing various activities of the Nano Mission and promote nano S & T in India for Indian industries and industrial associations FICCI, ASSOCHAM, and CII. It also plans to develop Indian patents database related to nanotechnology.

3.5.2.4. Outreach

In 2009, an English monthly magazines 'Nano Digest' and 'Nanoinsight' were launched with a purpose of disseminating information on latest research trend, outcomes and activities in nanotechnology activities in India. It can be seen as a new venue for various people in a research community to congregate and deliberate on the emerging issues of nanoscience and technology.

3.6 Nanotechnology Regulation and Risk Governance in India

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. Along with articulating a framework that looks into the factors that makes responsible development possible, existing sectoral regulations should be suitably modified to accommodate this technology.

Regulation is primarily concerned with anticipating and mitigating adverse impacts. The debate has now shifted towards developing institutional mechanisms for 'responsible development'. Regulation needs to cover different stages of the innovation process along with addressing risk issues at the upstream as well as downstream process. Nanotechnology needs to 'factor in' this approach while debating on best possible strategy to develop the regulatory framework.

In India, keeping in view the concerns of each sector, regulations particularly risk regulations have been created in different sectors i.e. a number of legislations are visible to address pollution control, environmental protection, hazardous waste disposal, biomedical waste disposal, safe manufacturing of drugs, occupational health and safety. Nanotechnology addresses myriads of sectors and has regulatory implications in the existing laws and regulations of different sectors. This is an important context that needs to be addressed for creating a proper regulatory framework for nanotechnology.

The broader agenda of governance for 'responsible development' is largely missing in existing legislations. It is more towards narrow framing of risk governance. Nevertheless, they have been drafted carefully and meet to a large extent the concerns in each sector. The issue is more towards their proper implementation. Possibly the first step would be to explicitly identify nanotechnology primarily nanomaterials as special class of materials which due to its distinct chemical and physical properties raises its own idiosyncrasies which cannot be accommodated within the present regulatory framework/laws and legislations within each sector.
This understanding at different policy levels can influence existing legislations in each sector to address nanotechnology risk aspects. Some of the countries have undertaken a large number of parallel actions to properly inform the policy community of nanotechnology regulatory issues. A reasonably high proportion of funding goes towards research on EHS and ELSI. This research is

very important for nanotechnology as there is major uncertainty and ignorance regarding the potential impacts of many manufactured nanomaterials on health and environment. Public debates/forums allow the various stakeholders particularly the public to participate/get informed of the different issues. The existing acts are being strengthened to accommodate nanomaterials. Green nanotechnologies are being promoted to address world's most pressing problems, such as clean water and climate change.

There have been concerns of what defines nanotechnology, how in the present patent framework nanotechnology is to be examined, standardization issues, etc. Task force, committees, guidelines/directives are being framed in the different countries in this regard. Separate institutions for risk governance are visible. These countries are moving towards innovation governance. In UK for example strategic actions are being proposed for engagements to strengthen the 'upstream' innovation process.

Risk regulation is required for each sector. In recent years, a couple of studies on the toxicity aspect have been initiated by DST, DBT, CSIR, ICMR and its various sister departments. The major objectives of these researches are to study the issues of toxicity, environmental and health implication of nanomaterials. Firms involved in nanotechnology based product development/products addressing water, textile, drug delivery have undertaken Life Cycle Analysis (LCA) partnering with research institutes/universities.

Toxicology studies are being carried out by the CSIR-Indian Institute of Toxicology Research (IITR), NIPER, CSIR- Indian Institute of Chemical Technology (IICT), and CSIR- Central Drug Research Institute (CDRI). In addition ICMR formulates, coordinates and promotes nanomaterial safety-related biomedical research in India. CSIR- National Environmental Engineering Research Institute (NEERI), CSIR-National Chemical Laboratory (NCL), CSIR- National Institute of Oceanography (NIO), Technology Information, Forecasting and Assessment Council (TIFAC), and ICAR are focusing on the effects of nanomaterials on human health and environment. NIPER is developing regulatory approval guidelines for nanotechnology based drugs and standards for toxicological tests in nano-based drug delivery systems. In 2010, DST appointed a task force which has been asked to advice Nano Mission Council to develop a regulatory body for nanotechnology in India.

Figure 3.6: **Nanotechnology Environmental Health Safety Research in India**

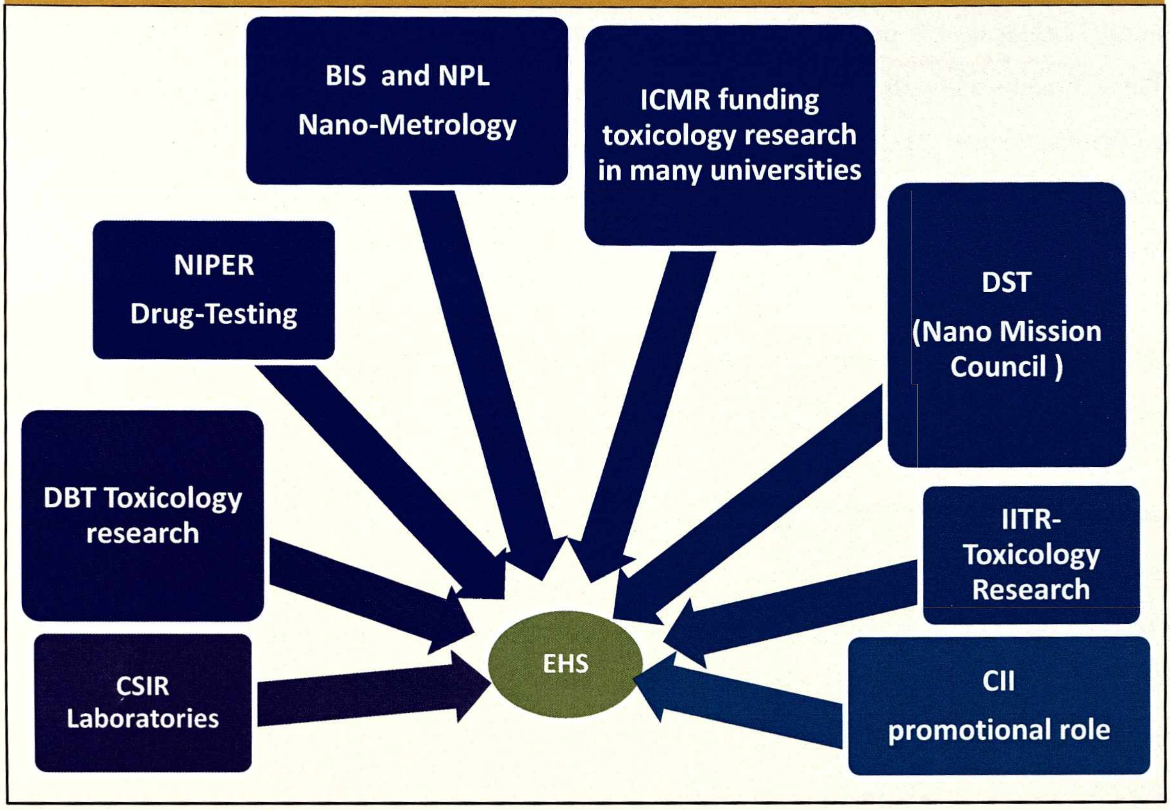
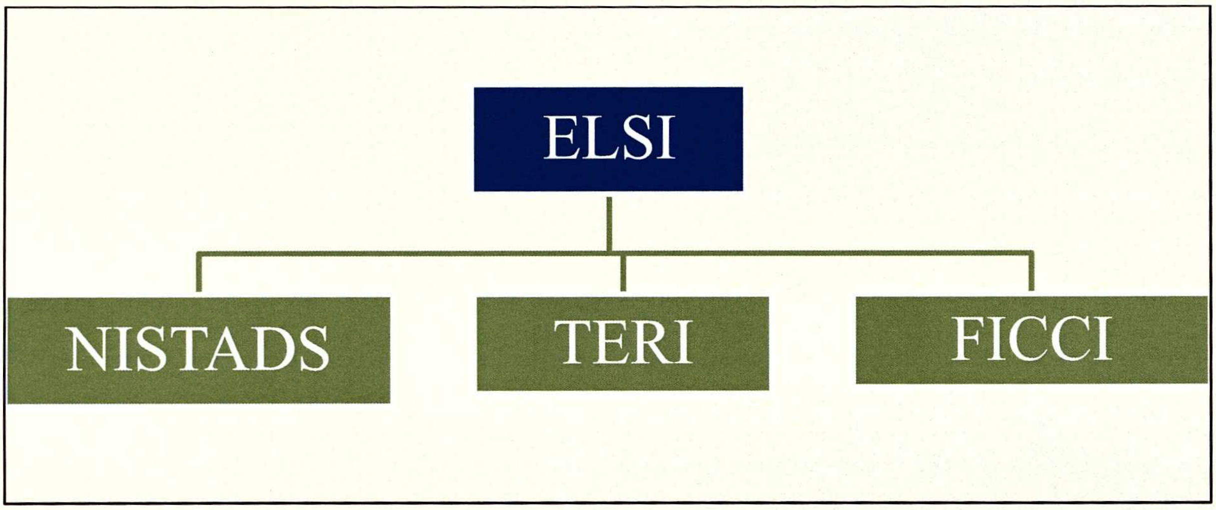


Figure 3.7: **Nanotechnology Ethical Legal Social Impacts of research in India**



Toxicological research in India and elsewhere has shown the hazardous properties of nanoparticles to human health. This concern is not only for biological applications where these materials are injected into human body but also during manufacturing and large scale production and external use. Another very important activity from nanotechnology development point of view is standardization activity. Accurate measurement of the dimension and physical, chemical and mechanical properties of nanomaterials is highly complex because of their small size and their minuscule response to any procedure used to measure a property. The properties of these materials vary widely from group to group. It is a great challenge for the International bodies who work in the area of standards to devise ways for standardization of the properties of nanomaterials. India has made a start in this area with Bureau of Indian Standards (BIS) initiating this process. In addition to this CSIR-NPL is focusing on standardization of dimensions, magnetic moment, optical emission and mechanical properties. It is also proposing Working Groups in these areas to ISO TC 229. DST also funded a standard development project in this area which is being undertaken by CSIR-NPL. ICMR is also involved in developing standard to medical applications of nanotechnology.

However, standardization activity remains an area of concern. In the absence of standards, nanotechnology commercialization would be affected. Opportunities and benefit of nanotechnology can only be realized within a clear regulatory framework that fully addresses the very nature of potential safety problems relating to nanomaterials. Regulation would also entail looking very closely at standards creation through linkages with international bodies and national ones.

3.7 Key Findings

The chapter highlights that India has been able to create a 'research ecosystem' in nanotechnology through multi-agency involvement with directed government programmes with separate budget allocation. Institutes across the country are getting involved in this area; specialized institutes with advanced facilities are being created, specialized university courses at different levels are being developed. Novel initiatives have been taken to allow researchers spread across the country to have access to advanced instruments. The industrial involvement in research is just beginning. However, it is encouraging to observe linkages with universities and research organizations. Extramural projects and conferences are providing opportunity of greater interaction and developing collaborative linkages.

Among the encouraging developments we observe institutes are now focusing on problem areas and thematic clusters in each sectoral domain are shaping up. The chapter argues that government initiative to promote thematic based development should be undertaken with a sectoral focus. It also shows that multiagency involvement has played a major role for developing the nanotechnology research ecosystem — creation of centers of excellence, providing researchers access to advanced instruments, funding support to universities for starting nanotechnology courses, development of model curriculum, initiating joint university-industry projects, national workshops/conferences with strong participation of students/young scholars and foreign experts. However, the chapter points out that commercialization of nanotechnology and development of skilled human resource have to be addressed by creation of more meaningful and functional linkages between existing institutions and developing novel partnership between academia and industry. Governance mechanisms, in particular risk governance and standards development requires urgent attention.

Anticipatory as well as participatory approach to innovation governance with different stakeholder involvement would have to develop in order to regulate nanotechnology.

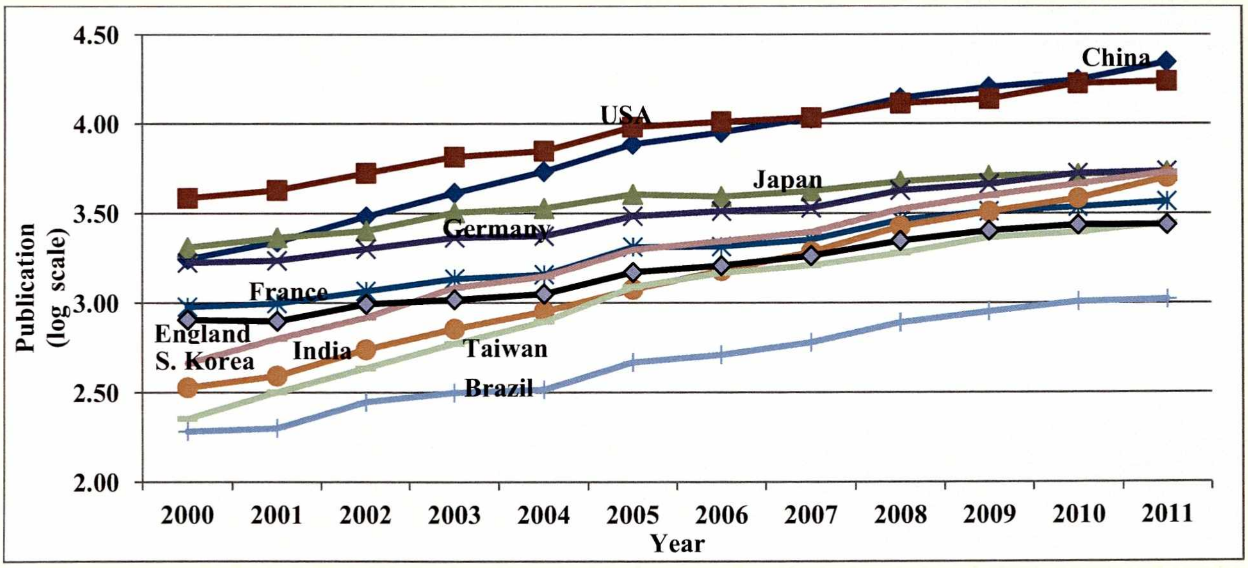
4. OUTPUT ANALYSIS

4.1 Publication Analysis

Nanotechnology publications increased significantly during the period 2000-2011 i.e. 13857 (2000) to 84774 (2011). This growth can be attributed to several reasons. One of the major driving factors is the large funding that countries have devoted to nanotechnology research; identified as a 'priority' research area in majority of advanced and emerging economies. It is important to note in this context, the involvement of emerging economies, newly industrialized countries, and even countries with limited scientific capacity. Among the other reasons include the prolific increase in nanotechnology journals. For example, the 'nanoscience and nanotechnology' journal category in the SCI-E covered 27 journals in 2005 which increased to 59 in 2005 and now in 2011 the number is 69. The general science journals and discipline specific journals are also devoting more attention to this field which allows further possibility of research papers from this area to be published in these journals. The increase in nanotechnology journals and inclusion of more papers in other journals signals the ever increasing importance of this area.

Figure 4.1 shows the publication trend of key advanced OECD and emerging economies.

Figure 4.1: **Publication activity of key advanced OECD and emerging economies**

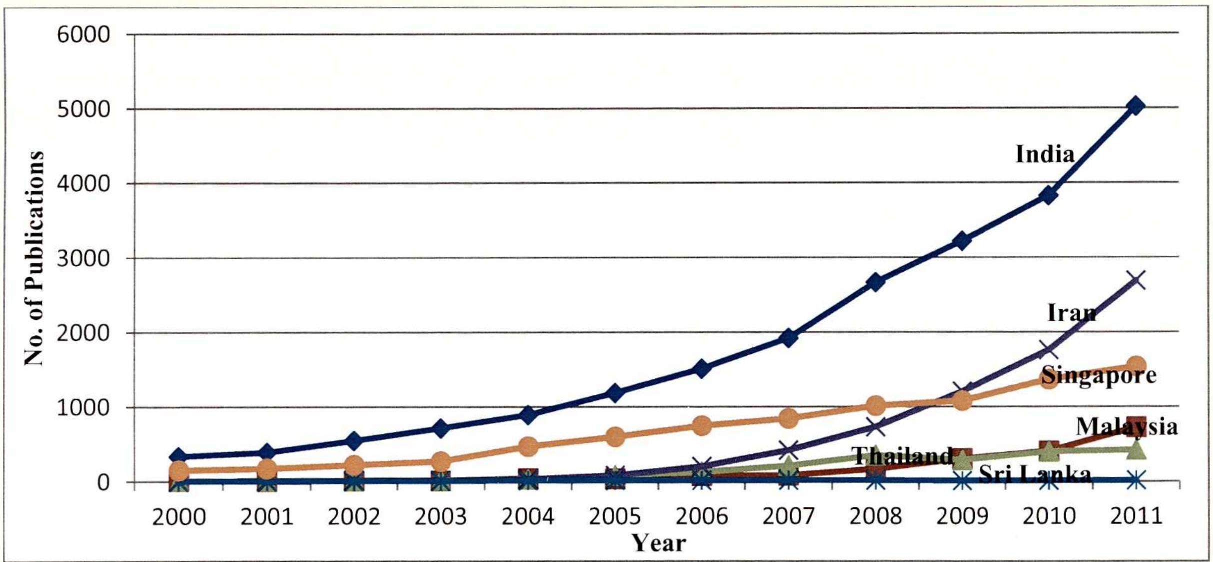


Source: Constructed from SCI-E; Search strategy based on Kostoff et al. (2006); Note: Refer Annexure II a for details

Publication aggregate for the complete period 2000-2011 shows India accounting for 21,981 papers (4% of the total world papers) in this field. India is now (i.e. in 2011), the 6th most prolific country publishing in the field. However, China has emerged as the most prolific country in research publications from 2009.[16] Nanotechnology is a highly science intensive field wherein technology development critically depends on scientific research. China leading in the publication race thus makes a strong statement. India also emerging as a key player in the global publication profile also assumes significance.

India's relative growth rate has been much higher than that of China from 2007 onwards (2000 taken as the base year). The maximum growth from year 2000 to year 2011 is shown by India (1394%) followed by China (1163%), Taiwan (1140%), and S. Korea (1064%) while prolific countries (primarily advanced OECD countries) i.e. Japan (165%), England (240%) and France (289%) shows least growth. Nanotechnology research is more widespread unlike some of the other cutting edge science based technologies wherein research is primarily restricted to a few countries having scientific capacity. Figure 4.2 shows the publication trends in nanotechnology of emerging economies in Asia (emerging defined in terms of scientific capacity).

Figure 4.2: **Emerging Asian countries making progress in nanotechnology**

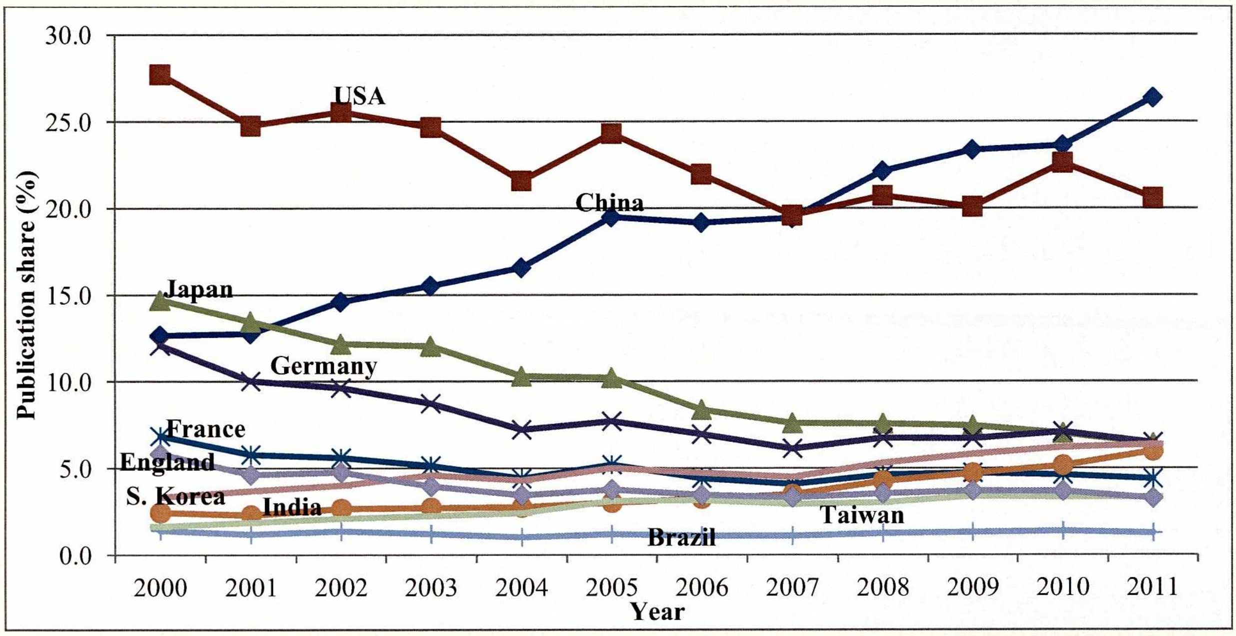


Source: SCI-E; Note: India taken as a benchmark for comparison; Note: Refer Annexure II b for details

[16] The actual number of papers among different studies show variations on account of different search criteria's as well as date of searching the database. Refer Methodology for further clarifications.

Iran has surpassed the other comparator countries. In 2011 it accounted for 2684 publications, acquiring a global rank of 10th in this field in this year.

Figure 4.3: **Publication share in nanotechnology**



Source: SCI-E; Note: Publication share (in percentage) is in terms of global output; Note: Refer Annexure II c for details

It can be observed from Figure 4.3 that the shares of countries are changing significantly over the years. Japan and to some extent Germany exhibits maximum decline. China, India, South Korea, and Taiwan have more contributions in the total global publication output in later years. This has helped them to move up in terms of international ranking. India for example has increased its publication share in nanotechnology over the years that resulted in it becoming 6th rank in the world in terms of publication output in 2011.

The trend of the global share i.e. contribution of each country to the total publications shows how the scenario is changing. Except for Asian countries, namely China, South Korea, Taiwan, and India, the global share of other advanced OECD countries are decreasing.

During the period 2000-2011, China accounted for 1,09,828 papers (20% of the total world papers) in this field. In, 2000 China accounted for 9.8% of papers and became a leader in 2009 with 23% of papers which increased to 26% of papers in 2011. India is much behind China, but it is making its presence felt. A steady rise in publication share is observed particularly from 2007 onwards. It accounted for 2% of total papers (global rank 13th) in 2000, 5% of the total papers in 2009 (global rank 7th), and 6% of total papers in 2011 (global rank 6th).

The dominant publishing countries (USA, Japan, and Germany) exhibit significant decrease in global publication share implying that relative publication growth has been less than other countries in the comparator group (China, India, S. Korea). USA accounted for 27% of nontechnology papers in 2000, 21% of papers in 2009 and 21% of papers in 2011. Sharp fall in publication share can be seen for Japan and Germany. In 2000, Japan accounted for 15% of papers and Germany 12% of papers while their shares in 2011 were 6% and 7% respectively.

4.1.1 Citation Reception: Indian Scenario

Table 4.1: **Publication and citation trends (India)**

Year	Publications	Citations	Citation per paper (in the year of publication)	Citations received in the year of publication (Uncited papers in the year of publication; %Uncited)	Uncited papers (%uncited)*
2000	247	8525	34.5 (0.2)	55 [213; 86%]	25 (10%)
2005	1072	15985	14.9 (0.3)	295 [777; 72%]	127 (12%)
2009	3086	14559	4.7 (0.4)	1364 [1869;61%]	762 (25%)
2011	5020	5260	1.0 (0.4)	2241 [3806;76%]	2674 (53%)

*Source: SCI-E; Note: * (Uncited papers/ papers) × 100*

India's publication activity has increased significantly during this twelve year period (2000-2011); 219% growth in 2005, 818% in 2009 and 1394% growth in 2011 (calculated from publication output in 2000). Citation measures provide view of reception of papers by the international community. Citations received and citations per paper are however strongly affected by the citation window, which the results also signify. *One important indication is how fast the papers from India are received by the international community?* We find in 2009, although the citation per paper was less but 42% of the papers received at least one citation. This indicates Indian research (particularly in 2009) is addressing important problems, relevant knowledge area which has gained the attention of the research community.

Further indication of reception was revealed by examining papers that were 'Above World Average Citation' (AWA)[17] papers, the papers in Top 10%, and those in Top 1% (which is the most stringent criterion and shows papers that are attracting the most attention). The Top 1% papers are creating major international impact and can be argued that these papers may have significant theoretical and/or experimental novelty that is helping draw the maximum attention of the research community.

The World Average Citation in 2000, 2005, 2009, and 2011 were 39, 92, 8 and 12 respectively.

Table 4.2: **Visibility of India in research papers**

Year	Total Output (Global Rank, % age Share)	Top 1% Cited Paper (Global Rank) [Collaborative papers]	Top 10% Cited Paper (Global Rank) [Collaborative papers]	AWA
2000	247 (13, 1)	3 (9) [1]	21 (14) [14]	58
2005	1072 (11, 5)	6 (14) [4]	41 (15) [18]	17
2009	3086 (7, 14)	26 (13) [17]	168 (9) [78]	695
2011	5020 (6, 23)	16 (14) [12]	317 (9) [130]	1395

*Source: SCI-E; Note: % Share – (Output of the year x/Total world output in year x) * 100*

Table 4.2 shows that a significant number of papers from India are receiving citation below the world average. This shows that although India is emerging as an important player (6th rank in 2011), but is not able to draw considerable attention of the research community in this field.

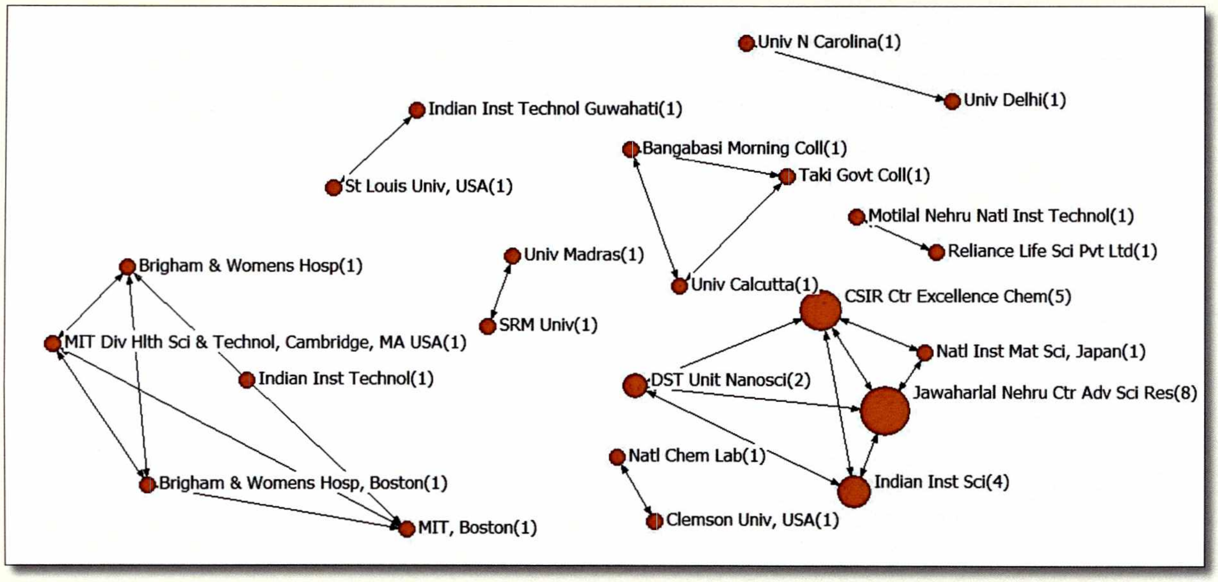
17 'AWA' indicates the number of papers above the world average citation in the respective year. World Average Citation is the ratio of number of citations received by total papers published in nanotechnology in a year divided by total papers of that year.

India's publication activity is increasing over the years and they are attracting more attention than before. Collaboration is playing an important role in this regard.

The AWA is high in 2005 and this probably accounts for India having much lesser number of papers above world average. However, better performance is observed in terms of papers present in Top 10% and Top 1% cited papers. India is performing better in 2011 in AWA but the papers in Top 1% is less than earlier periods. However, conclusion may not be drawn of citation reception from figures in 2011, as they will change, as the citation window will increase (the longer the time period between a paper being published and citation counting, larger is the probability of citation reception). Still there is a cause of concern as India is in the top ten most active players in terms of research papers as reflected in the SCI-E; their papers are not attracting attention to that extent. Characteristic feature in the highly cited papers of India is that majority of these papers are result of authors from different institutions collaborating with each other.

Figure 4.4 below highlights the linkages among the TOP 1% cited papers in 2009.

Figure 4.4: **Linkages among institutions in the top 1% cited papers (2009)**



Note: Analysis using Bibexcel and Graph using UCINET. Bracket qualifies the number of papers of that institute in the Top 1% cited papers. Refer Annexure II d for the papers.

Collaboration is playing an important role in papers getting high degree of visibility. The linkages show geographical proximity as well as diversity.

Among the 26 papers from India in the Top 1% cited papers in 2009, 65% of papers (17 papers) are collaborative papers. Two key clusters are observed from the above figure; one formed by the public sector institutions such as CSIR-COE[18], DST, JNCASR, IISc, and National Institute of Material Science (Japan), and another cluster is between Indian Institute of Technology (IIT's) and foreign institutions. The linkage between CSIR-COE and JNCASR indicates the in-house institutional linkages. Other institutions are scattered and display individual linkages with one or more Indian or foreign institutions.

[18] In January 1991, the CSIR established the Centre of Excellence in Chemistry in JNCASR. The Centre works on various aspects of solid state and materials chemistry.

4.1.2 Citation Reception: Global Scenario

Table 4.3: **Visibility of top five countries in research papers (2000, 2005, 2009)**

Country	2000				2005				2009			
	Total Output (Rank)	Top 1% Cited Paper (Rank)	Top 10% Cited Paper (Rank)	AWA	Total Output (Rank)	Top 1% Cited Paper (Rank)	Top 10% Cited Paper (Rank)	AWA	Total Output (Rank)	Top 1% Cited Paper (Rank)	Top 10% Cited Paper (Rank)	AWA
China	1314 (4)	3 (6)	81 (3)	224	6512 (2)	30 (3)	362 (2)	189	14329 (1)	132 (2)	1072 (2)	2592
USA	3344 (1)	68 (1)	475 (1)	1284	10453 (1)	155 (1)	1150 (1)	729	13553 (2)	257 (1)	1904 (1)	4940
Japan	1661 (2)	7 (3)	77 (4)	346	3740 (3)	19 (4)	193 (4)	105	4743 (3)	44 (7)	295 (4)	1084
Germany	1388 (3)	9 (2)	132 (2)	436	2845 (4)	35 (2)	237 (3)	147	4298 (4)	103 (3)	462 (3)	1443
S. Korea	320 (14)	2 (10)	25 (12)	86	1894 (6)	8 (9)	118 (7)	63	3787 (5)	48 (6)	286 (5)	910

Source: SCI-E

Table 4.4: **Visibility of top five countries in research papers (2010-2011)**

Country	2010				2011			
	Total Output (Rank)	Top 1% Cited Paper (Rank)	Top 10% Cited Paper (Rank)	AWA	Total Output (Rank)	Top 1% Cited Paper (Rank)	Top 10% Cited Paper (Rank)	AWA
China	17532 (1)	177 (2)	1802 (2)	5091	22132 (1)	230 (2)	2251 (2)	7195
USA	16783 (2)	358 (1)	2679 (1)	6371	17288 (2)	340 (1)	2598 (1)	7264
Japan	5206 (4)	45 (4)	449 (4)	1338	5382 (4)	58 (4)	484 (5)	1663
Germany	5270 (3)	75 (3)	704 (3)	1925	5430 (3)	71 (3)	734 (3)	2276
S. Korea	4608 (5)	35 (6)	408 (5)	1237	5344 (5)	51 (6)	489 (4)	1631

Source: SCI-E

Table 4.3 and Table 4.4 shows that China has become a leader in publication race in 2011 but its citation reception rate is still low. Citation normalized by total output (this adjusts for size) in each category (Top 1%, Top 10%), provides a more informed picture of major impact country's paper make (citation assumed as proxy for impact). Table 4.5 highlights this normalized citation profile (citation adjusted by size i.e. research papers) for some prolific publishing countries.

Table 4.5: **Normalized citation profile of some prolific publishing countries**

Country	2000	2005	2009	2011
	Top 1%/ Top 10%/ AWA	Top 1%/ Top 10%/ AWA	Top 1%/ Top 10%/ AWA	Top 1%/ Top 10%/ AWA
China	0.2/ 6/ 17	0.5/ 5/ 3	0.9/ 7/ 18	1/ 10/ 33
USA	2.0/ 14/ 38	1/ 11/ 7	2/ 14/ 36	2/ 15/ 42
Japan	0.4/ 5/ 21	1/ 5/ 3	1/ 6/ 23	1/ 9/ 31
Germany	0.6/ 9/ 31	1/ 5/ 8	2/ 11/ 34	1/ 14/ 42
S. Korea	0.6/ 8/ 27	0.4/ 6/ 3	1/ 8/ 24	1/ 9/ 31
India	0.6/ 6/ 7	1/ 4/ 2	0.8/ 23/ 23	0.3/ 6/ 28

In spite of significant publication increase in both China and India, their papers are not cited to that extent when compared to other countries with prolific research papers. This contrast is visible more in the Top 1% and Top 10% cited papers.

Table 4.5 shows that in spite of China and to some extent India leading in the publishing race, its visibility among the research community is lagging in comparison to other countries with much lesser number of publications. There is however a silver lining as the citation normalized figures is much greater for China in 2009 in comparison to 2000 and 2005 in spite of the number of papers (denominator) increasing significantly. Similar to China, India is also improving its ratio in later years.

4.1.3 Publication Activity: Journal based delineation

Table 4.6: **Journals where India is publishing actively and activity in high impact factor journals (2000-2011)**

Active Journals (IF)	Total Papers (% world share)	High IF Journals	Total Papers (% world share)	Collaborative Papers (%)*	Citations Received (CPP)
Journal of Nanoscience and Nanotechnology (1.563)	661 (10.9%)	Nature Nanotechnology (27.270)	3(0.4%)	2 (67%)	386 (129)
Journal of Applied Physics (2.168)	571 (5.7%)	Nano Today (15.355)	1 (0.37%)	-	89(89)
Journal of Physical Chemistry C (4.805)	441 (4.9%)	Nano Letters (13.198)	26(0.46%)	5 (19%)	2152 (83)
Applied Physics Letters (3.844)	378 (2.5%)	Small (8.349)	33 (1.7%)	19 (58%)	617 (19)

Active Journals (IF)	Total Papers (% world share)	High IF Journals	Total Papers (% world share)	Collaborative Papers (%)*	Citations Received (CPP)
Journal of Alloys and Compounds (2.289)	371 (9%)	Lab on a Chip (5.670)	2(0.59)	1 (50%)	19 (10)
Materials Letters (2.307)	351 (8.4%)	Nanomedicine (5.055)	23 (4.05%)	9 (39%)	407 (18)
Physical Review B (3.691)	331 (2.3%)	ACS Nano (10.774)	28 (1.05%)	15 (54%)	472 (17)

*Source: SCI-E; Note: IF=>Impact Factor, CPP=>Citations received per paper, *Percentage denotes the share of collaborative papers*

Collaboration is playing an important role in paper getting published in top journals. This corroborates the role of collaboration in attracting attention of the research community — Top 1% and Top 10% cited papers.

Table 4.6 underscores two points: (a) India is publishing in journals with reasonably high impact factor. However, in the top IF journals in this field, Indian activity are insignificant; (b) Majority of papers in the top journals are collaborative (authors from different institutions).

4.1.4 Nanotechnology Papers in Different Subject Categories

In terms of total output during the period 2000-11 India's research activity is prominent in 'material science', particularly in areas covered under 'material science' (multidisciplinary) (28685 papers). The other areas of major research focus are: 'electrical engineering electronics' (25167 papers), and 'chemistry multidisciplinary' (23664 papers). Some of the areas where high growth rates are observed: 'chemistry organic' (17839), 'biochemistry molecular biology' (15544), and 'pharmacology pharmacy' (14483).

Table 4.7 highlights the activity of top six publishing countries in different sub-disciplines of nanotechnology from 2000-2011.

Table 4.7: **Activity of top five countries in different sub-disciplines of nanotechnology**

Country	Publication 2000-11 (Rank)	% World share [2000], [2009], [2011]	Publication 2000-11 (Rank)	% World share [2000], [2009], [2011]	Publication 2000-11 (Rank)	% World share [2000], [2009], [2011]	Publication 2000-11 (Rank)	% World share [2000], [2009], [2011]
	Physics		Physical Chemistry		Applied Physics		Biochemistry	
China	17436 (2)	[7], [20],[16]	18001 (2)	[5], [25],[21]	47619 (2)	[9],[19],[14]	4453 (1)	[7],[26],[20]
USA	28561 (1)	[29], [26], [26]	18758 (1)	[29], [22], [22]	71277 (1)	[26], [19], [22]	4288 (2)	[24],[18],[19]
Japan	11073 (3)	[14], [9], [10]	9570(3)	[17], [9],[11]	45871 (3)	[17],[11],[14]	2469 (3)	[16],[9],[11]
S. Korea	5787 (6)	[2], [6], [5]	6270 (5)	[4], [8],[7]	25145 (5)	[5],[8],[8]	1110 (6)	[12],[7],[5]
Germany	9921 (4)	[14], [8], [9]	6789 (4)	[12], [7],[8]	29045 (4)	[11],[8],[9]	1943 (4)	[3],[5],[9]
India	3344(11)	[1], [4], [3]	2993 (9)	[3], [4],[4]	13343 (8)	[2], [5],[4]	905 (9)	[2], [5],[4]
	Chemistry		Analytical Chemistry		Material Science		Macromolecules	
China	19542 (2)	[6],[20],[15]	20834 (1)	[15],[30],[24]	49443(1)	[11],[29],[23]	51438 (2)	[10],[26],[20]
USA	37122 (1)	[33],[25],[28]	17689 (2)	[21],[18],[20]	40039 (2)	[24],[15],[18]	55536 (1)	[27],[20],[22]
Japan	10555 (3)	[11],[7],[8]	9055 (3)	[16],[8],[10	21532 (3)	[14],[8],[10]	28884 (3)	[16],[9],[11]
S. Korea	4971(9)	[10],[7],[4]	4668 (5)	[8],[6],[7]	12470 (5)	[9],[6],[6]	17099 (5)	[10],[7],[7]
Germany	9782 (4)	[3],[4],[7]	5999 (4)	[3],[5],[5]	15458 (4)	[5],[5],[7]	19973 (4)	[5],[6],[8]
India	6766 (6)	[2], [6],[5]	3451 (7)	[1], [5],[4]	9731 (7)	[11], [1][4]	10180 (8)	[2], [5],[4]

Source: SCI-E; Note: Search Strategy based on Mogoutov and Kahane (2007)

USA leads in publishing papers in nanotechnology in five different subject categories: Applied Physics (71,277 papers), Macromolecules (55,536 papers), Physics (28,561 papers), Chemistry (37,122 papers) and Physical Chemistry (18,758 papers). In other three major subject fields, China has maximum number of nanotechnology papers: Material Science (49,443 papers), Analytical Chemistry (20,834 papers) and Biochemistry (4453 papers). Activity in different subject fields provides indication of sectoral research strength and competency. For example, China is among the leaders in 'Nano material applications' and its research activity in this field is an indication of this. This table also shows that China and India are the only country, which has shown increase in publication share (2000-2011) among the active publishing countries in every sub-discipline.

Table also highlights India's nanotechnology activity in different disciplines— overall and snapshot activity in three years 2000, 2009, 2011. It shows its nanotechnology research activity closely corresponds with its publication strength in these areas.

4.1.5 Institutional Activity

Institutions involved in publishing activity in 2009 increased more than three-fold from that of 2000 (from 423 to 1349 institutions). The most prolific institutes are highlighted in Table 4.8.

Table 4.8: **Activity of prolific Indian institutes (2000-11)**

Institutions	Number of Publications (2000-11)	Collaborative Papers (% of Collaborative Papers)
IISc	1390	751 (54)
IIT-Kharagpur	1253	702 (56)
IACS	1028	607 (59)
BARC	993	715 (72)
CSIR-NCL	899	602 (67)
IIT-Madras	816	555 (68)
IIT-Delhi	790	593 (75)
CSIR-NPL	764	649 (85)

Note: *%age rate of growth => (Y-X)/X × 100 (2009 to 2011); IACS => Indian Association for the Cultivation of Science; BARC => Bhabha Atomic Research Center

Institutions of prolific activity are reputed academic institutions and research laboratories. Out of the eight institutes listed, six namely IISc, IIT-Kharagpur, CSIR-NCL, IACS, IIT-Madras, IIT- Delhi are Centres of Excellence (COE). COE's are observed to play an important role in strengthening the research activity in this field.

For more in depth analysis we analyzed the publication data from five most prolific institutions for the period 2000-2009. The table below summarizes the key important results. IISc is the most prolific institutions followed by IIT-Kharagpur, CSIR-NCL, IACS, and BARC.

Table 4.9: **Analysis of publications from five most prolific institutions**

	IISc	CSIR-NCL	IACS	BARC	IIT-Kharagpur
Years 2000 | 2005 | 2009	24 | 87 | 229	24 | 99 | 89	16 | 56 | 156	11 | 47 | 152	27 | 72 | 173
Total publications (CPP) [2000-09]	951 (17)	726 (20)	706 (11)	618 (10)	860 (11)
Collaborative publications [% of collaborative papers] (CPP)	523 [55] (20)	315 [43] (22)	300 [42] (10)	350 [57] (11)	306 [36] (11)
Industrial collaborative papers (Number of unique industries involved)	13(10)	13 (4)	2(2)	4(2)	1(1)
Total publications growth rate (2000-09)	9	3	9	13	5
Collaborative publications growth rate (2000-09)	6	11	4	31	8
Most active area of publication-Number of papers (growth rate 00-09)	Applied Physics- 602 (1)	Macromolecules 474 (2)	Applied Physics- 434 (3)	Material Science- 386 (3)	Material Science- 602 (2)

Note: CPP=>Citation per paper; Growth rate=>(y-x)/x

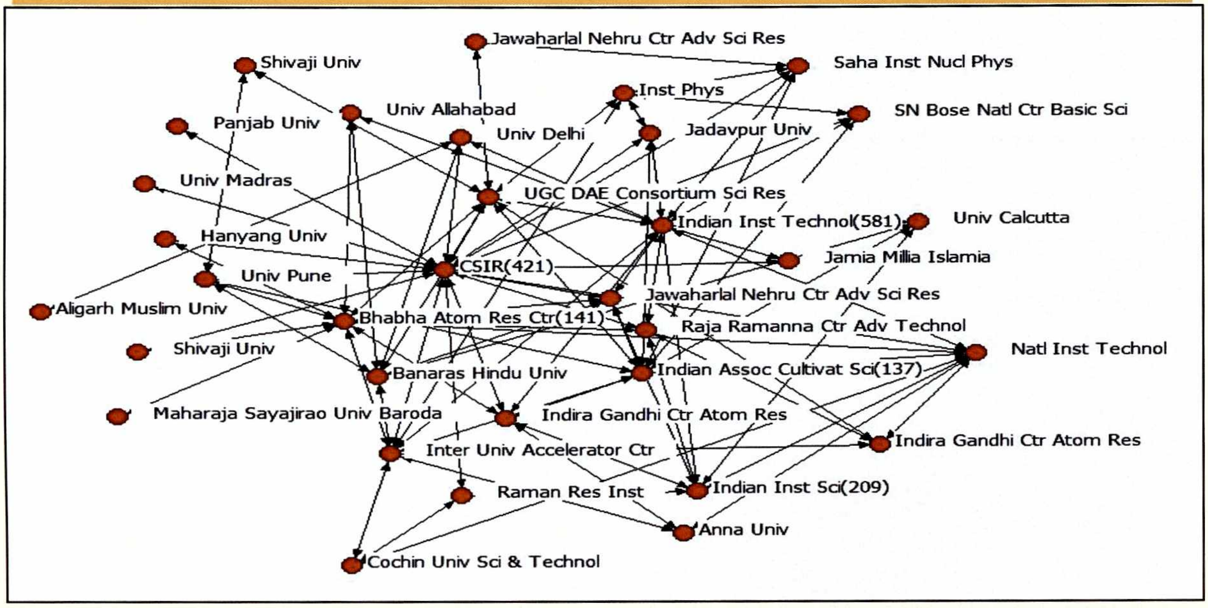
Nanotechnology Involvement of Prolific Institutes

IISc is exploring nanotechnology interventions in different disciplines— among the key areas are nanodevices, nanocomposites and nanobiosensors. CSIR-NCL is applying nanotechnology in development of green energy technologies (major focus areas: polymer electrolyte membrane fuel cells, solid state supercapacitors, and MEA based gas sensors). IIT- Kharagpur is undertaking research for nanotechnology based interventions in biotechnology, material science, nanocomposites, electronics, etc. IACS is undertaking nanotechnology research in semiconductors, electronic devices (energy transfer), and superconductor. BARC is applying nanotechnology in improving material efficiency such as in thin films and coatings.

4.1.5.1 Collaborative Linkages among Institutions

The collaborative papers involving different institutes are increasing in later periods. In 2000, 37 percent of the total papers involved at least two authors from different institutes (92 out of 247 papers published), whereas in 2009, 47 percent of total papers were collaborative papers involving different institutes (1450 out of 3086 papers). Figure 4.5 shows the most active collaboration among institutions in 2009.

Figure 4.5: **Collaborative linkages among most active institutions (2009)**



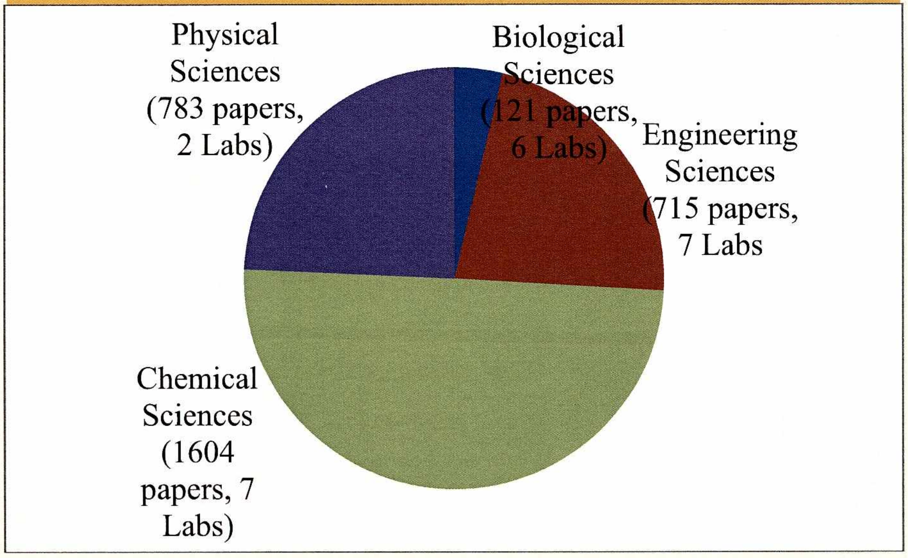
Note: Analysis using Bibexcel and visualization using Pajek. CSIR includes aggregated research publications of its 37 laboratories. IIT includes aggregated publication activity of all the seven IIT's.

Institutional linkages are developing from sparse network (2000) towards a more connected network in 2009. Cluster formation has strong bearing on geographical proximity. This formation may be due to sharing of sophisticated capital intensive instrument required for nanotechnology research.

As a group/entity, CSIR and IIT's are publishing maximum number of papers— 2193 and 2784 papers respectively (research period 2000-2009). There has been a significant rise in research output in both these entities in past two years i.e. 2010 and 2011. The aggregated publication in this period (2010 and 2011) of CSIR increased by 47% to 3213 papers, and IIT by 55% to 4309 papers from the earlier period (2000-2009). This increasing research output of CSIR and IIT's has played a major role in the publication increase from India in this field.

Figure 4.6 highlights the broad distribution of CSIR nanotechnology papers among major CSIR thematic clusters.

Figure 4.6: Publication activity of CSIR laboratories (2000-2011)



Source: SCI-E; Note: Refer CSIR Annual Report for Laboratories under each group

Table 4.10 highlights the CSIR's nanotechnology papers in different sub domains. NCL and NPL, first one a chemical laboratory and second a physical laboratory with 899 and 764 papers are dominating CSIR publications.

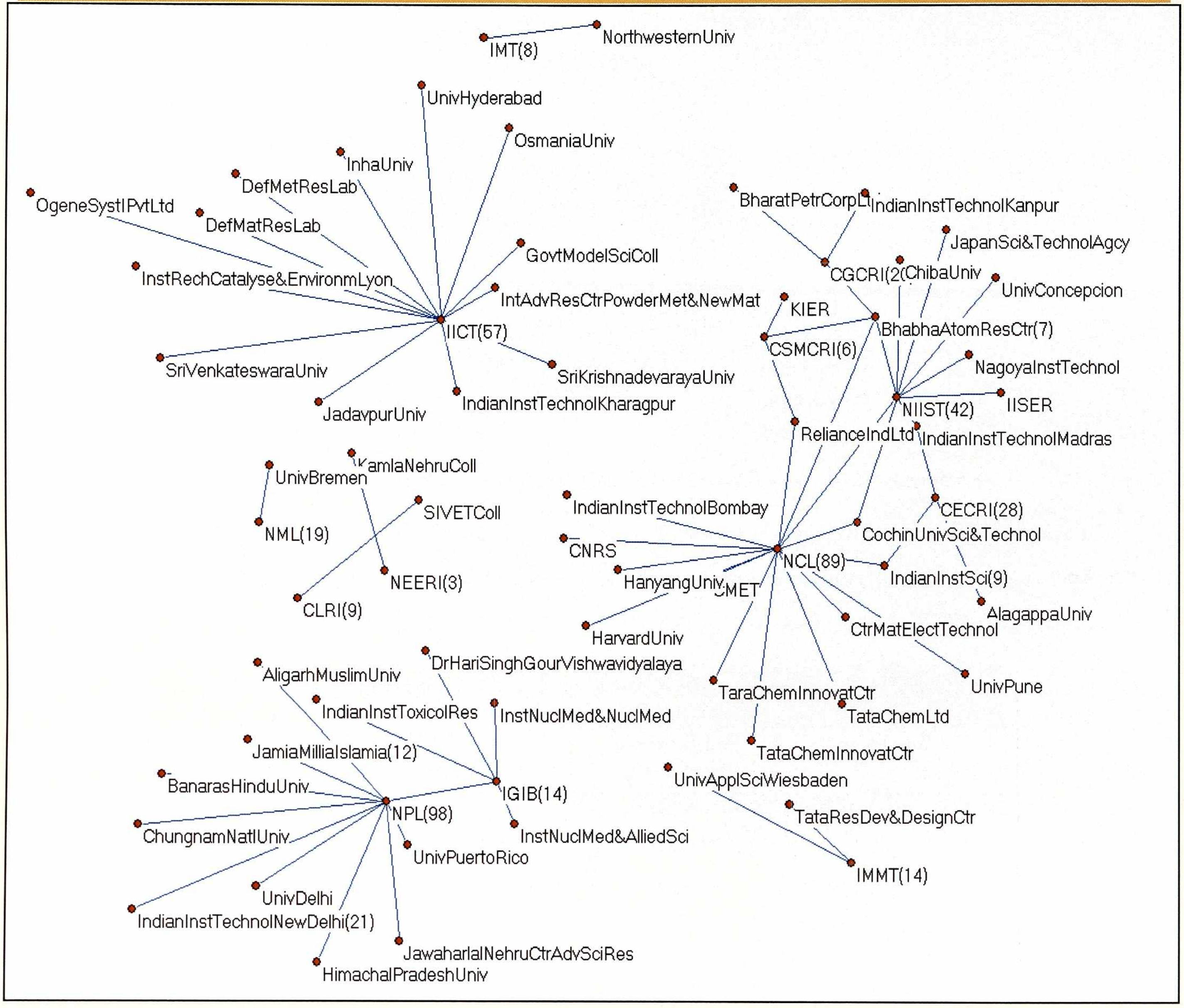
Table 4.10: CSIR contribution in different subject areas within nanotechnology (2000-2009)

Subject	Publications from India	CSIR Publications (Percent contribution by CSIR)
Macromolecules	6701	1301 (20)
Applied Physics	9423	1042 (12)
Material Science	6988	1007 (17)
Chemistry	4309	652 (35)
Physics	2009	297 (15)
Physical Chemistry	1803	278 (17)
Biochemistry	566	198 (15)

Note: Based on search string by Mogoutov and Kahane, 2007

As the table highlights, CSIR is playing an important role in increasing research capacity in different sectors. Nanotechnology research by CSIR in chemistry is particularly significant. The research collaboration (as visible through research papers) of CSIR laboratories in 2009 is shown in Figure 4.7.

Figure 4.7: **Research collaboration in CSIR laboratories (2009)**



Note: Analysis using bibexcel and visualization using pajek

Varied linkages are observed with Universities, IIT's and research institutes. Industrial collaboration is also visible. Some foreign universities are also visible in the network. Geographical proximity is playing an important role in collaboration. For example, out of 106 papers of CSIR-NPL in 2009, 71 papers are collaborative papers. Among these collaborative papers, 53% were from the institutes in close proximity- University of Delhi (accounting for 35% of CSIR-NPL collaboration), IIT-Delhi (28%), and Jamia Milia Islamia University (13%).

Table 4.11: **Major collaborators of prolific CSIR laboratories (2009)**

CSIR-NPL (98 papers)	CSIR-NCL (89 papers)
University of Delhi (25) IIT-Delhi (20) Jamia Milia Islamia (9) Himachal Pradesh University (5)	University of Pune (12) Shivaji University (5) CSIR-NIIST(4) Cochin University (4)
CSIR-IICT (57 papers)	**CSIR-NIIST (42 papers)**
Defense Metallurgical Laboratory (5) Inha University (5) Osmania University (4) ARCI (3) University of Hyderabad (3)	CSIR-NCL (4) University of Concepcion (3) IISER (3)

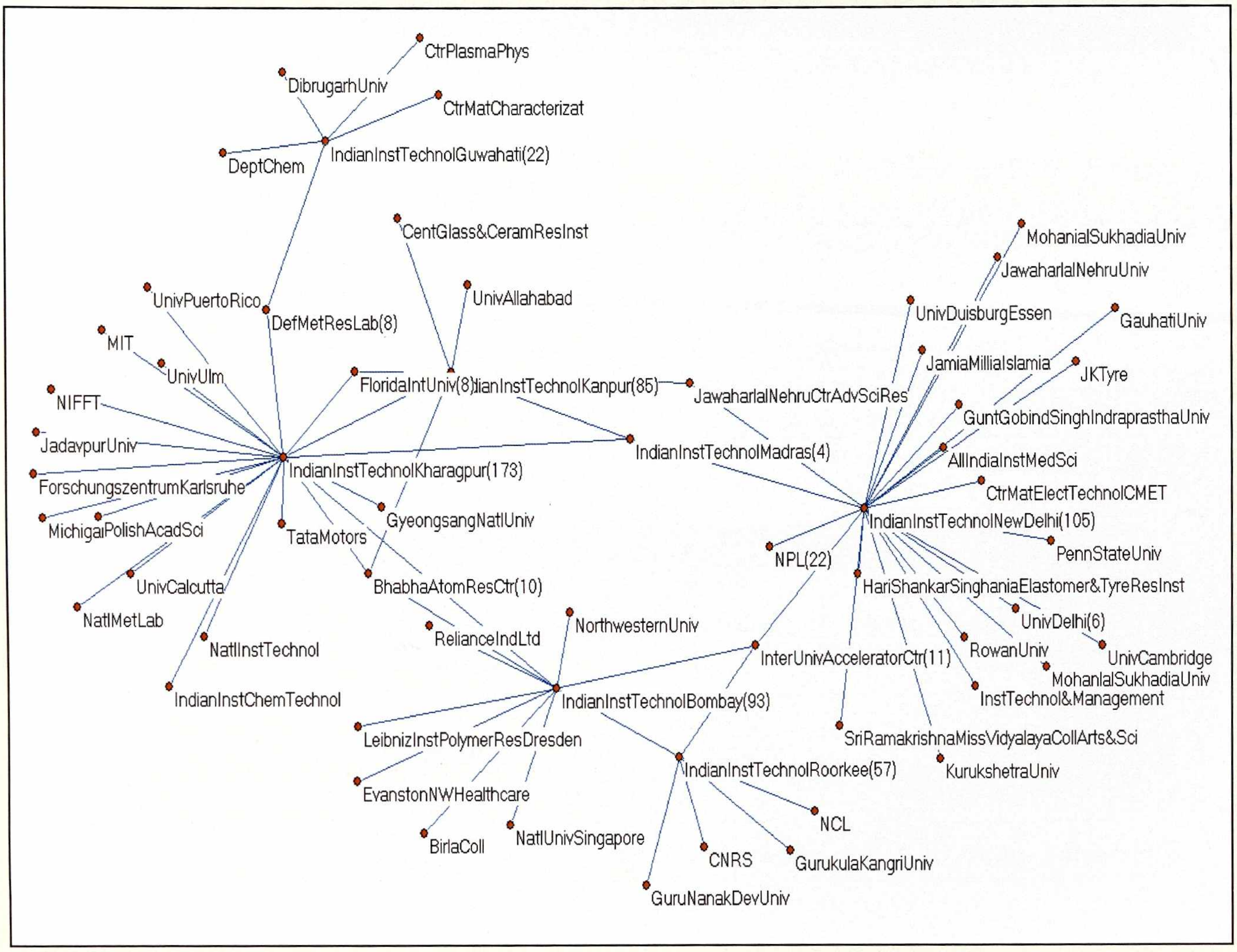
Table 4.12: **Number of publications from IITs (2000-11)**

Indian Institute of Technology's (IITs)	No. of Publications	Indian Institute of Technology's (IITs)	No. of Publications
IIT-Kharagpur	1253	IIT-Kanpur	478
IIT-Madras	816	IIT-Roorkee	250
IIT-Delhi	790	IIT-Gwahati	148
IIT-Bombay	574		

Publications from IIT's are visible in diverse areas of nanotechnology, i.e. biotechnology, electronics, nanocomposites, sensors etc. Aggregated output of the period 2000-2011 shows IIT-Kharagpur (1253 papers) is the most prolific among the IIT's followed by IIT-Madras (816 papers), and IIT-Delhi (790 papers).

Figure 4.8 shows the collaboration linkages in research papers of Indian Institutes of Technology in 2009.

Figure 4.8: **Research collaboration in IIT's (2009)**



Note: Analysis using Bibexcel and visualization using pajek

Geographical proximity is playing an important role in collaboration. Each of the old established IIT's has their own core network. However they are also inter-connected to each other. Some of the industrial linkages observed are IIT-Delhi—JK Tyre; IIT-Bombay—Reliance India; IIT-Kharagpur—Tata Motors etc. IIT's are actively collaborating with the foreign institutions.

4.1.6 Industrial Research Activity

In a science intensive technology like nanotechnology, publication signifies more than just an indication of scientific strength. Publication also provides an indication of capability and absorptive capacity of a firm. Some bigger companies like Reliance Industries, Tata Chemicals, Mahindra and Mahindra have initiated programmes in the area of nanomaterials on their own or in collaboration with academic/R&D institutions.

Table 4.13: **Publication activity by industry**

Year	Industrial Papers (CPP)	Collaborative Papers (CPP)	CP-Universities	CP-CSIR	Publication share (%) of industrial papers
2000	1 (26)	1 (26)	1		0.4
2001	3 (8)	3 (8)	1	1	0.8
2003	4 (16)	4 (16)	4		0.6
2004	3 (17)	3 (17)	1	2	0.3
2005	4 (37)	4 (37)	2	3	0.4
2006	16 (13)	13 (16)	4	10	1.1
2007	25 (9)	21 (10)	16	10	1.3
2008	26 (5)	22 (6)	13	6	1.0
2009	37 (5)	30 (6)	21	7	1.1
2010	45 (3)	41 (3)	37	3	1.2
2011	55 (1)	45 (1)	37	8	1.1

Source: SCI-E; CPP=>Citations per paper; CP=>Collaborative papers by industries

Only a few firms are involved in publishing activity. Industry affiliated papers are highly collaborative, and are mainly occurring with universities or CSIR laboratories.

The firms actively publishing are Ogene Sys (22 papers), Reliance (16), Tata Steel (12), Monad Nanotech (7), and Tata Chemicals (6). Out of 219 industry-affiliated papers, 187 papers (85%) were collaborative papers (2000-11). Some important industrial collaboration includes IICT—Ogene Systems (22 papers), IIT-Bombay—Reliance (11), Monad Nanotech—Birla College (7), Tata Chemicals—CSIR-NCL (6). Majority of the collaborations are with the academia or with CSIR laboratories. Active collaboration of CSIR laboratories with industry as visible in the industrial research papers indicates CSIR's fruitful academic partnership with industry. This relationship can play an important role in translational research and commercialization.

Table 4.14 lists the Industries collaborating with the prolific institutions for publishing research papers.

<table>
<tr><th colspan="3">Table 4.14: Firms collaborating with the most prolific institutions</th></tr>
<tr><th>IISc</th><th>CSIR-NCL</th><th>BARC</th></tr>
<tr><td rowspan="3">Datar Switchgear
NED Energy
Rigaku Americas Corporation
Exxon Mobil Research & Engineering Company
Materials and Electrochemical Company
Nanoco Technologies
Orbifold Solutions
Tata Steel</td><td>Reliance
IBM Co.
Tata Chemicals
United Phosphorus</td><td>Monad Nanotech
SHM</td></tr>
<tr><th>IACS</th><th>IIT-Kharagpur</th></tr>
<tr><td>Nanoco Technologies
Jubilant Chemsys</td><td>Tata Steel</td></tr>
</table>

Majority of the firms involved in research activity are showing active collaboration with universities/CSIR-laboratories. Some firms have invested in this technology at an early stage; estimated to have invested over 1.2 billion rupees (30 million USD) in nanotechnology R&D. Reliance and TATA Chemicals have set up their own R&D centers in Pune (Maharashtra).

A rough estimate of researchers involved in nanotechnology research in India can be calculated from authors publishing papers in this field. Based on unique author identification[19], 15,562 authors were identified (research period 2000-2011).

[19] There are various types of errors such as wrong author spelling, common names, etc. Another problem is that only first alphabet of the author name is given. For corrections/validations, matching of authors with institution was undertaken. But still this method only provides a very rough estimate.

Table 4.15 exhibits publication profile of most prolific authors during the period 2000-09.

Table 4.15: **Most prolific authors from India**

Author's Name	Affiliated Institution	Number of Publications 2000-2009	Number of Publications in Top 1% cited papers			Number of Publications in Top 10% cited papers			Number of Publications in AWA papers		
			2000	2005	2009	2000	2005	2009	2000	2005	2009
Rao CNR	JNCASR	216			8	6	1	11	9		17
Sastry M	CSIR-NCL	195		2		1	4		5	2	2
Kumar A	JNCASR	148		1	2		2	5	2	1	13
Chaudhuri S	IACS	136								2	
Tyagi AK	BARC	132									10
Kumar R	IUAC	124						5	2		9
Avasthi DK	IUAC	112									1
Pal T	IIT-Kharagpur	97					1		2		4
Govindraj A	JNCASR	95									
Kar S	IACS	92		2			4	1	1	2	11

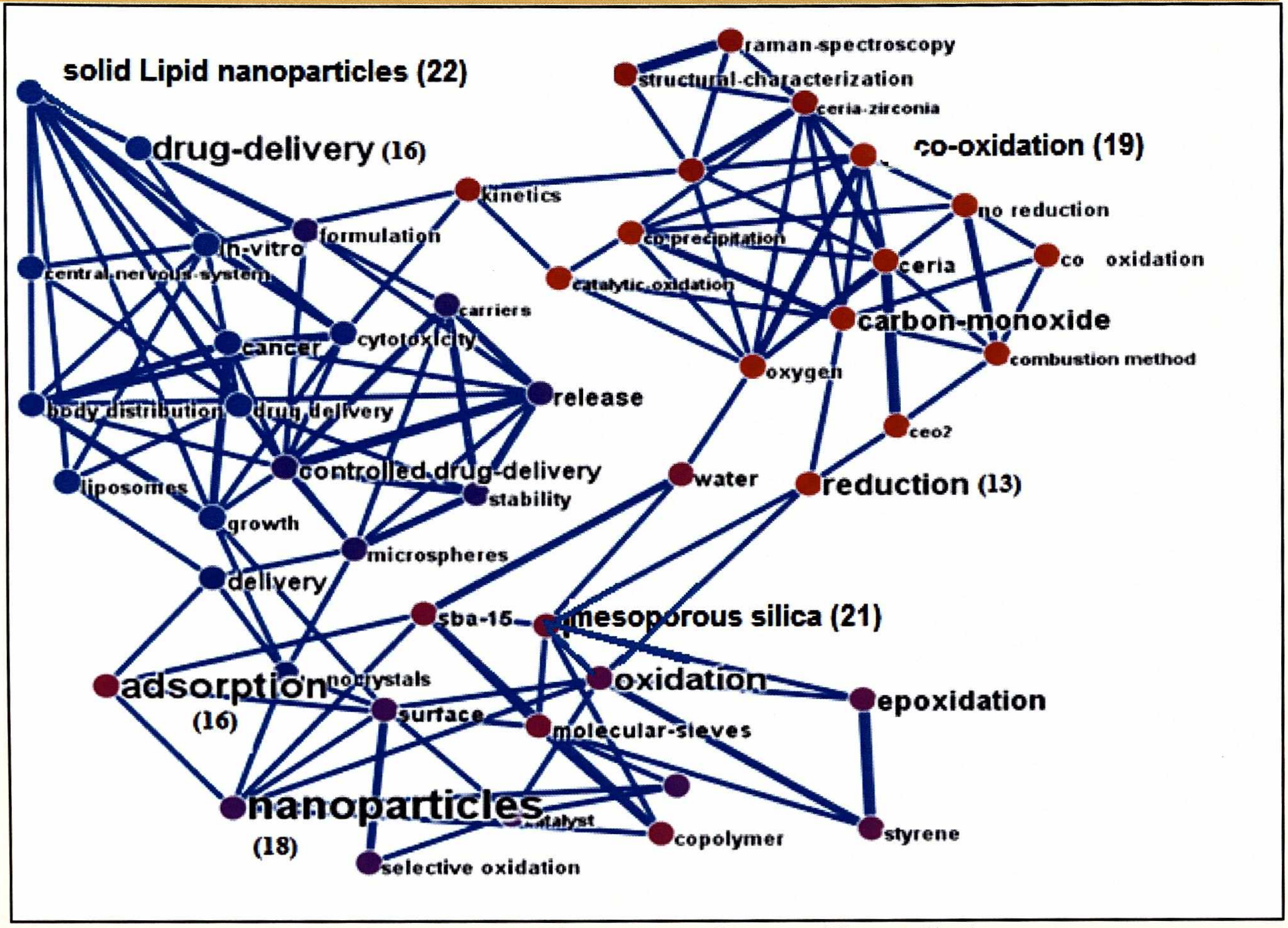
Note: Common surnames may lead to some difference from the actual, a problem which can occur in collaborative papers among institutes. Exact delineation is not possible as only first alphabet is given for a name [6]

4.1.7 Content Analysis

The frequency of occurrence of keywords in the research papers highlight concepts that are prominent whereas linkages among them indicate topics where maximum research is taking place.

In 2000, inorganic nano-materials like copper, silver, palladium, structures like thin film, powder are the most frequently occurring keywords. Connections are also observed among them in the linkage map showing nanostructures are appearing in powder, thin film and particles form. Lack of instrument specific to characterization of nanotechnology indicates that characterization has been done with the existing spectroscopy instrumentation like Infrared spectroscopy (also visible in the linkage map). In 2005 we observe presence of various instruments in the network specific to characterization of optical, mechanical, physical and chemical properties of nanoparticles e.g. Scanning electron microscopy (SEM), Transmission electron microscopy (TEM), and X-Ray photoelectron spectroscopy. Along with the frequently occurring sophisticated instruments, drug delivery, catalyst, gold nanoparticles are also observed. Linkages are observed in the map indicating research taking place in drug delivery system with gold nanoparticle as probably being researched in terms of carrier and/or catalyst. Figure 4.9 exhibits keyword linkages of Indian papers in 2009.

Figure 4.9: **Linkage among active keywords (2009)**



Note: Analysis and visualization using Citespace (Chomni Chen)

In comparison to 2000, and 2005 we find more directional and applied research in 2009. In 2009, as the figure 4.9 shows, the network is maturing with focus on applied research namely in biomedical, water, and environmental mitigation. New nanoparticles are also observed.

4.2 Patenting Activity

4.2.1 US Patent Office

Total 10,951 patents were filed (2001-2011) under 'Class 977: Nanotechnology' in the US Patent Office (USPTO). USA filed 2675 patents (25% of overall filing), followed by Japan 761 patents (7% of patents filed) and South Korea 626 patents (6% of overall filing), and Taiwan 535 patents (5% of total contribution).

Changing trends are visible in the later years in the nanotechnology patent applications filed in the USPTO. One of the striking finding is the emergence of China. Table 4.16 highlights this changing dynamics.

Table 4.16: Applications in the USPTO by key advanced OECD and emerging economies

Country	2001-2003		2004-2006		2007-2009		2010-2011	
	Total Patents	% Contribution	Total Patents	% Contribution	Total Patents	% Contribution	Total Patents	% Contribution
USA	38	15.7	119	11.7	792	22.7	1726	28
Japan	6	2.5	45	4.4	227	6.5	483	8
S. Korea	0	0	15	1.5	147	4.2	464	7
Taiwan	0	0	11	1.1	179	5.1	345	6
China	1	0	4	0.4	123	3.5	240	4
Germany	1	0.4	10	1	68	1.9	192	3

Source: http://patft.uspto.gov/netahtml/PTO/search

Table 4.16 points out the highly skewed nature of patenting activity particularly in the first two block periods with USA and Japan the dominating countries. South Korea shows a very strong progress but China's progress is remarkable! China applied for only one patent in block period 2001-03, four patents in the block period 2004-06, but in 2010-11 it has substantial filing and is accounting for 4% of filing in this patent office (5th rank as per filing during this period).

Total 5509 patents were granted (2001-2011) under 'Class 977: Nanotechnology' in the USPTO. The maximum patents were granted to USA (3235 patents; 56% of overall grant) followed by Japan (7593 patents; 14% of overall grant) and South Korea (390 patents; 7% of overall grant). Table 4.17 highlights how many applications have been successful.

Table 4.17: Patents granted by the USPTO to key advanced OECD and emerging economies

Country	2001-2003		2004-2006		2007-2009		2010-2011	
	Total Patents	% Contribution	Total Patents	% Contribution	Total Patents	% Contribution	Total Patents	% Contribution
USA	945	59.1	612	57.6	829	62	849	53.9
Japan	220	13.8	161	15.1	173	13	205	13
S. Korea	42	2.6	60	5.6	91	6.8	197	12.5
Taiwan	21	1.3	37	3.5	56	4.2	90	5.7
China	1	0.06	7	0.6	28	2.1	50	3.2

Country	2001-2003		2004-2006		2007-2009		2010-2011	
	Total Patents	% Contribu-tion	Total Patents	% Contribu-tion	Total Patents	% Contribu-tion	Total Patents	% Contribu-tion
Germany	74	4.6	29	2.7	34	2.5	36	2.3

Source: http://patft.uspto.gov/netahtml/PTO/search

Box 4.1: University-Industry Joint Patenting Activity in the US Patent Office

One of the striking features of China's patenting trend is the joint patenting activity between university and industry, particularly visible in applications filed. Patenting activity of Hon Hai Precision, and Tsinghua University and their joint filing is striking in this patent office. Hon Hai filed 158 patents and Tsinghua university 121 patents of which 118 patents were jointly filed during the block period 2007-09 in the USPTO. They held rank 1 and rank 2 in terms of highest filing in this patent office during this period i.e. 2007-09.

For the period 2001-09, Hon Hai filed 167 patents, Tsinghua University 125 patents and jointly 121 patents. Further introspection shows interesting aspects of their collaborative linkages.

Tsinghua University is a leading university of China, part of C9 league that comprises the top 9 universities in China and is among the top 100 universities in different global university rankings. Hon Hai Precision Industry is a Taiwan based entity, commonly known by its trade name Foxconn is the world's largest contract electronics manufacturer. Hon Hai created the Tsinghua-Foxconn Nanotechnology Research Center (TFNRC) which is located within the campus of this university. This center concentrates on application of carbon nanotubes, backed up by basic research. Among important products developed by this centre include electrical connections to replace copper wires, yarns for co-axial cables and various types of films for applications such as electromagnetic shielding and field emissions. They have also produced nanotube based touch-panel displays with prototype screens that have applications in mobile phones, etc. The technology being developed is aggressively patented with intellectual property being shared jointly between the university and the company.

The examination of their joint patents provides an indication of the inventive capability that is developing over the years in China. The patents in the early applications by this centre are in varied methods of growing carbon nanotubes. Later patents address specific applications of carbon nanotubes i.e. yarn (textile), microscopic electronics, nanoscale integrated circuits, nano based display panels (for computer, LCD, TV and mobile screen). Later patent applications also address lithium battery, composite material for automotive, carbon based array sensors and electron emission device. Thus we observe joint patenting activity is not only strengthening over the years but are also directed to specific applications.

Similar to patent application statistics in this area, we observe a skewed distribution in patents granted to various countries. USA and Japan are dominating; South Korea, Taiwan, and Germany are also active players. Patent granted to China shows substantial increase from 2007 onwards, similar to its filing activity during this period. China has surpassed Germany in the patent granted during the block period 2010-11.

Five sub-classes under 977 are dominating international patenting activity during the period; in each of these sub-classes, more than 200 patents were filed. Three sub-classes are under Nanostructure ('CNTs', 'Nanowires or Quantum Wires' and 'Crystallographic Terraces and Ridges'), while two sub-classes are 'Drug Delivery' and 'Support System for DNA Analysis' (are part of specified use of nanostructure). Apart from this, some other active areas include application of electromagnetic properties, virus based particle, single walled and multi-walled nanostructures, fullerenes or fullerenes like structures.

Table 4.18: **Activity of different countries in sub-classes of 977 in the USPTO (2001-11)**

Description Application [Grant]	Nanostructure (977700)	Mathematical algorithms for modeling configurations (977839)	Manufacture, treatment or detection of nanostructure (977840)	Specified use of nanostructure (977902)	Miscellaneous (977963)
USA	2811 [1938]	10 [6]	750 [1109]	1767 [873]	5 [13]
S. Korea	614 [234]	-	154 [147]	232 [969]	1 [1]
China	294 [64]	-	79 [38]	139 [19]	-
India	26 [14]	-	10 [9]	17 [9]	-
World	8048 [3649]	18 [11]	2070 [2563]	4207 [2369]	7 [24]

Note: Refer Annexure III a for detailed description of sub-classes

4.2.2 PCT Applications

Total 1819 applications were filed in the WIPO under the international classification code 'B82' during the research period 2001-2011. Most of the filings are from USA (735 patents, 40% of global filings) followed by Japan (372 patents, 20% of global filings) and South Korea (295 patents, 16% of global filings).

Table 4.19 highlights the PCT applications of active countries.

Table 4.19: **PCT applications by key advanced OECD and emerging economies**

Country	2001-2003		2004-2006		2007-2009		2010-2011	
	Total Patents	% Contribution	Total Patents	% Contribution	Total Patents	% Contribution	Total Patents	% Contribution
USA	33	56	53	20	321	44	328	42
S. Korea	3	5	27	10	85	12	180	23
Japan	8	14	114	44	179	25	71	9
Germany	4	7	15	6	6	1	32	4
China			2	13	11	2	13	2

Source: http://patentscope.wipo.int/search

Table 4.20 provides the activity of different countries in the sub-classes of B82.

Table 4.20: **Activity of different countries in sub-classes of B82 (2001-11)**

B82 sub class	Nano-technology (Global Patents)	USA	China	Japan	S. Korea	Germany
B82B	**Nano-structures formed by manipulation (1678)**	**694**	**25**	**362**	**292**	**42**
B82B1	Nano-structures formed by manipulation (782)	351	10	214	69	20
B82B3	Manufacture or treatment of nano-structures by manipulation (1299)	498	21	283	265	32
B82Y	**Specific uses or applications of nano-structures (167)**	**56**	**1**	**11**	**7**	**23**
B82Y5	Nano-biotechnology (29)	9		2		2
B82Y10	Nano-technology for information processing, storage or transmission (23)	13	1			3
B82Y15	Nano-technology for interacting, sensing or actuating (30)	8		2	2	2
B82Y20	Nano-optics (13)	1		3		3
B82Y25	Nano-magnetism (6)	1				
B82Y30	Nano-technology for materials or surface science (63)	18		4	3	12
B82Y35	Methods or apparatus for measurement or analysis of nano-					2

	structures (2)					
B82Y40	Manufacture or treatment of nano-structures (49)	26		1		5
B82Y99	Subject matter not provided for in other groups of this subclass (1)					

Note: Refer Annexure III b for the detailed description of the sub-classes

B82 is classified into two main sub classes i.e. B82B and B82Y which are described as 'nanostructure formation and manipulation' and 'specific uses or application of nanostructures respectively'. Around 90% of patents are filed under the category B82B while 10% are filed under B82Y globally. The lesser number of patents are filed under the category 'nano magnetism (B82Y25)', 'methods or apparatus for measurement or analysis of nano-structures (B82Y35)' and 'miscellaneous (B82Y99)'.

4.2.3 Indian Patenting Activity in International Patent Offices and Domestic Patent Office

Table 4.21: **Indian patenting activity**

	USPTO Applications	USPTO Grant	PCT Applications	IPO* Applications	IPO* Grant	IPO** Applications	IPO** Grant	EPO Applications	EPO Grant
2001-03	-	5	1	-	-	30	16	4	-
2004-06	-	3	1	2	-	68	28	12	6
2007-09	1	1	6	7	6	175	2	10	2
2010-11	19	2	3	9	1	-	-	15	2

*Note: *Search strategy (IPC class B82); **Search strategy (nano*), USPTO (class 977)*

4.2.3.1 US Patent Office

Indian patenting in nanotechnology is just beginning in the USPTO. Only twenty patents were filed during the period 2001-11; one filing in 2007-09 and nineteen filings in 2010-11 respectively. Only a few entities are involved in patenting activity but the number is increasing in later period. Fourteenn entities are involved in patent filing activity. These include JNCASR, DRDO, CSIR, IIT-Madras, IISc, Tata Chemicals with two patent respectively and Sunev Pharmaceuticals Solutions, Laila Pharmaceuticals, IIT-Bombay, IACS, University of Calcutta, Lifecare Innovations, Sun Pharmaceuticals with one filing each.

Eleven patents were granted during this period (2001-2011); five patents granted during 2001-03 and three patents in 2004-06, only one patent in 2007-09 and two patents in year 2010-11. Patents have been granted to only four entities: CSIR (7 patents), Torrent Pharmaceuticals (1 patent), IISc (1 patent) and University of Mumbai (1 patent).

Box 4.2: Focus of Indian Patents in the USPTO

The areas where India is involved in patent filing and grant activity are 'Nanostructure based therapeutic compounds', 'Chemical process based manufacture of nanostructure' and 'Chemical compound to treat disease'. Most of the patents from India are having biological focus; for example biodegradable polyesters in pharmaceutical compositions, process of immobilizing enzymes, liposomal formulations for oral drug delivery, nutritional supplements to prevent various diseases. Apart from biological patents some other areas include sensor device, rechargeable batteries and semiconductors, magnetic nanomaterials for enhanced absorption capacity.

Some patents seem to provide new pathways to advance technology with novel solutions. Sensor patents by Ajay Sood's group in IISc are one example of this. This group made international news in 2002 when they generated electricity by making a fluid flow through single-walled nanotubes. The discovery led to an entirely new class of nanosensors. Concept Medical Research applied for patents in the US and India for introducing nano particles to release drugs to block cell proliferation in the narrowed diseased coronary arteries. This is the first patent filed of this kind anywhere in the world to release drugs into the diseased coronary arteries. The present solution is through stents, which although are bio-absorbable but being made of polymers can create complications of inflammation, clotting and toxicity.

4.2.3.2 European Patent Office

Total 16462 applications filed in the EPO under ECLA classification code 'B82' during the research period 2001-2011. Most of the filings are from USA (5343 patents) followed by Japan (3680 patents). Forty one patents were filed by nineteen institutions during this period. Most prolific institutes are CSIR (10 patents), Tata Chemicals (2 patents), USV Ltd. (2 patents) and Cipla (2 patents).

Total 3983 patents were granted in class 'B82' during the period 2001-2011. Most of the grants are from USA (1194 patents) followed by Japan (1009 patents) and South Korea (122 patents). Ten patents were granted to four institutions: CSIR (6 patents), USV (1 patent), Cipla (1 patent) and Bharat Serums and Vaccines (1 patent).

Box 4.3: Focus of Indian Patents in the EPO

Some novel applications are visible in EPO from India like fast reheat bottle grade polyethyleneteraphthalate resin with features like fast absorbing heat during bottles making course, low energy consumption, high yield per unit time and high productivity; DNA based arithmetic; method for energy conversions; dye sensitized solar cells. Some other key areas of patents are glass sensing applications, therapeutic compounds, decontaminating water from pesticides, antimicrobial agents, anesthetic compositions and inclusion complex (esomeprazol and opioid peptide).

4.2.3.3 PCT Applications

Eleven patents were filed in the WIPO by Indian applicants. Total seven Institutions are involved in patent filing activity from India. It includes CSIR (2 patents), IIT Madras (1 patent), IISc (1 patent), JNCASR (1 patent), Savic Innovative Plastics (1 patent), Panacea biotech (1 patent) and Yeda (1 patent) and three individual patents.

Ten patents were filed in B82B subclass which includes the formation and manipulation of nanostructures while only one patent filed under the subclass B82Y which is the specific uses or application of nanostructure. Specifically this one application is under subclass B82Y15 'Nano-technology for interacting, sensing or actuating'.

Box 4.4: Focus of Indian Patents in the WIPO

Patents includes process for the preparation of polymer composites, CNTs as energy harvesting devices, antimicrobial composites, metal nanosponge, polymeric foams, coatings, active ingredients for drug delivery and silver nanoparticles (antimicrobial activity).

4.2.3.4 Indian Patent Office (IPO)

Total 61 applications were filed in the IPO under the IPC code 'B82' during the period 2001-2011. The major filing countries are USA (20 patents) followed by India (18 patents) and Sweden (6 patents). Total nine institutions were involved from India in patent filing activity IIT (3 patents), CSIR (3 patents), Agharkar research Institute, IPCA Laboratories, Crystal Nanoclay, Tata Chemicals, Dalmia Institute of Scientific and Industrial Research, Bharati Vidyapith, North Maharashtra University with one patent each, and five individual patents.

Total 12 patents were granted under the IPC code 'B82' during the period 2001-2011. Seven patents were granted to India, three to USA and one each to China, and France. Four Institutions were granted patents from India: IIT (3 patents), CSIR (2 patents), Agharkar Research Institute and IPCA Laboratories (1 patent each).

To capture the interrelated patents the search string nano* was used. Based on this search string, 970 patent applications were found (data upto 2010). 101 patents have been granted till then. USA (342 applications), India (273 applications), and Germany (51 applications) were the countries primarily involved in patent filing in the IPO. In all patent filing has come from 16 countries. 42 institutions are involved in patent filing activity from India. Academia is dominating the patent filing activity. CSIR (81 patents) is the key player involved in patent filing in this field. Firms actively involved are Ranbaxy, Lifecare Innovations, and Futura.

Box 4.5: **Focus of Indian Patents in the IPO**

Patents from India are primarily process patents. The process patents cover processes for the manufacture of CNTs, metal sulfides, gold metal nanoparticles, silver nanoparticles, ultra nanofilms of metals, semiconducting nanotubes, nanosized titanium dioxide, colloidal metal nanoparticles, nanosilica, palladium nanoparticles and nanocomposite materials.

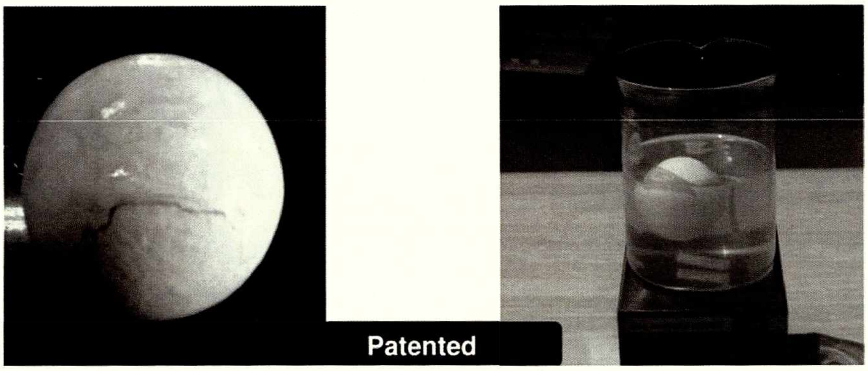
The nanomaterials and nanocomposites patents claim have applications in drug delivery, semiconductors and ICT.

Box 4.6: **Patents by CSIR Laboratories (Patestate Database)**

More informed assessment of CSIR patenting trend in nanotechnology can be observed by analyzing patenting activity from CSIR's patestate database (www.patestate.com/). As nanotechnology is not marked as a separate in this database, the search string nano* was used. Cleaning was done to remove noises.

Total Patents 81 covering this field for the period 1997-2012 with 26 patents in the USPTO and 51 patents in the IPO. Six patent filing offices could not be identified. The patents granted to CSIR are mainly process patents for nanoparticles, nanocrystalline compounds, nanostructures, CNTs, thin films etc. Applications of these are visible in semiconductors, paints and coatings, optical circuits, magnetic storage devices, sensors, LEDs and photonics. Apart from this applications are also visible in the biological field: immunoprobes, analgesics/antiinflamatory, medical diagnostics, targeted drug delivery and prebiotics. This shows the range of areas CSIR is involved.

Water Disinfectant



4.3 Standards

Standard creation, recognition internationally, and its adoption is an important component in making a country's dominant presence in a technology. This is more so for an emerging technology and for a country with a large domestic market, as technical standards created by it in a particular product class can become a key strategy for dominating internal market and influence future adoption of that standard internationally.

It is important to see an emerging economy like China, among a few countries involved in developing standards for nanotechnology. China has developed a range of standards; initiating this process from 2003 onwards with different agencies involved in this process and was the first country to issue national standards for nanotechnology in April, 2005.

India in spite of significant progress has not paid due attention to nanotechnology standard creation. Standard activity is not explicitly articulated in India's nanotechnology plan and implementation documents. Bureau of Indian Standards (BIS), CSIR-NPL, Nano Mission and DIT are the key stakeholders in the standard creation activity. CSIR-NPL is the national metrology institute of the country and thus the development of technical standards in nanotechnology falls within its mandate.

The Bureau of Indian Standards (BIS) coordinates the overall standardization activity in the country, is the national standards authority and is an autonomous body under the Ministry of Consumer

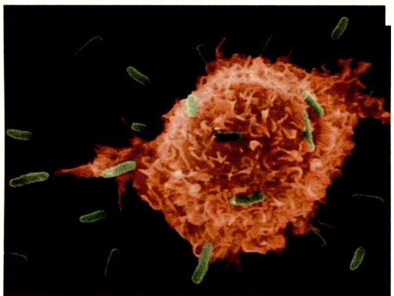
Affairs, Food and Public Distribution (MCA). It is involved in standards formulation and the certification of products and systems. In 2010, BIS set up two sectional committees:

1) MTD 33 for nanotechnology, which liaises with the corresponding international committees (ISO/TC229/WG2) on measurement and characterization. Nano devices, sensors, transistors, initiators and atomic force microscopy have all been identified as priority areas by MTD 33.
2) MHD 21 for medical biotechnology, which deals in the ISO/TC229/ WG 3 on the health, safety and environmental aspects of nanotechnologies.

So far two standards are at the test stage: National standard on use of Atomic Force Microscope for characterization and evaluation of nanomaterials, and electron microscopic characterization of multi-wall carbon nanotubes. The remaining two standards proposed are: Luminescent nanomaterials and magnetic nanoparticles, and standard on toxicity of Zinc Oxide nanomaterials

4.4 Products and Processes Developed

Prototype automotive oil filter



Nanotechnology based cancer treatment

Woodrow Wilson database is an international inventory of nanotechnology products. This database contains 1317 items (covered up to the year 2011). Thirty countries show their presence in this database. USA, Germany, South Korea, China, and Japan have major presence with 587, 168, 126, 55, and 51 products respectively. Majority of the products (60% of the total products) globally are in health and fitness segment. India just entered in the list with two personal care products (St. Botanica Nano Breast Cream, St. Botanica Pueraria Nano Breast Serum).

Table 4.22 highlights the major product category in this database.

Table 4.22: **Nanotechnology based products**

Application area	**Products in each categories**	**Product Types**
Health & Fitness	604	Air sanitizer/purifier, functional sportswear, nano fabric, nano filtration membrane system, silver foam condom, texcote textile processing, makeup instrument, lipobelle co-enzyme, water proof
Home & Garden	152	Antibacterial pet product, water tap
Food & Beverage	92	Antibacterial pet product, water tap, chop sticks, nano refrigerator oriental health card, nano silver storage box
Automotive	70	Global products (Sealing, car polishes, fuel bornecatalyst, tire)
Electronics & Computers	57	Lenovo think station, OLEDs (Organic Light Emitting Diode), antibacterial pay phone
Diversified	55	Anti bacterial (Locks, instrument, products, tableware, watch chain, water tap, paint supplement) and self cleaning coating
Appliances	37	Car air purifier, refrigerator, air conditioner filter, AC filter liquid antibacterial deodorant spray.
Goods for Children	19	Nano Plush Toys

Source: http://www.nanotechproject.org/inventories/consumer/

Products are not visible in two key medical segments where nanotechnology based applications can play a key role namely drug delivery and therapeutics, and biosensors and medical devices. This may be due to the limitations of this database as they focus on product and not process inventory.

Indian firms and research organizations shows a more active profile in application development in the domestic market. India, although was a late starter, but has shown promise with its research and have developed few applications which can make global impact.

Key areas where application developments are visible are highlighted.

a) Biomedical/Pharmaceuticals

University of Delhi has developed a process of entrapping genetic materials in nanoparticles of inorganic compounds to form non-viral carriers. This technology has been transferred to American Bioscience Inc., USA. IIT-Bombay has developed a cardiac diagnosis product using nanotechnology that provides exact reading of an individual's heart. This is already being used in many hospitals in India. 'Lifecare innovations' have developed, the only amphotericin B formulation of the world that is almost free of nephrotoxicity - a formulation problem that remained unsolved for sixty. An important instrument for nanotechnology research, the nanofluid interferometer used for biomedical research has been developed by an Indian firm.

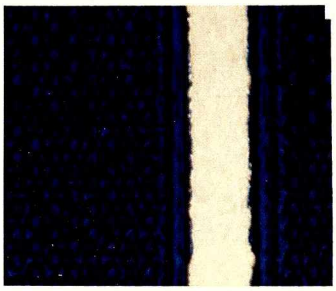
Albupax

Fungisome

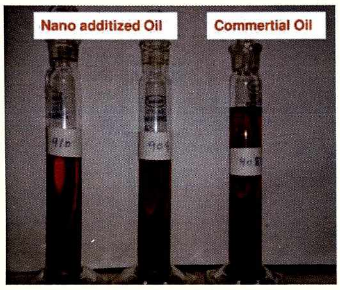
En-Tube capsules

b) Energy

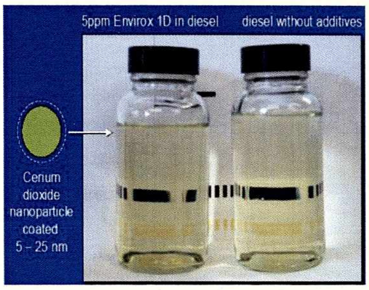
Researchers are working to create efficient and cost effective nano-enabled solar photo-voltaic cell. Moser Baer has active collaboration with CSIR-NCL and CSIR-NPL in this area. High efficiency dye-sensitised solar cells at the lab level have been developed. This can have important economic and social outcomes.



Photovoltaic solar cell



Nanotechnology in Lubricant research
(Indian Oil R&D)
(self cleaning)



Nanotechnology in Fuel
(Indian Oil R&D)

c) Water

Nanotechnology interventions have helped develop advanced water filter. The institutes involved in this area are: CSIR (nanotechnology based water filter); ARCI and SBP Aquatech Pvt. Ltd (Puritech); Tata chemicals (Tata- Swatch); Aquaguard Total by Eureka Forbes Ltd. and IIT- Madras (nanotechnology based solution to remove pesticides from water).

Tata Swach

Puritech

ARCI has developed a number of applications over the last few years. One of them is the low cost nanosilver-coated ceramic candle for disinfection of drinking water. The center has also filed an Indian patent for the same process. In 2009, ARCI installed 100 nanosilver candle based water filter systems for field testing at various village health centers in Andhra Pradesh in collaboration with Byrraju Foundation. During the field testing these filters demonstrated a consistent performance in removing the bacteria from the water. Now this application is available in the market in the name of 'Puritech'.

Four products from ARCI have already been transferred to the industry, including a water filter system for rural areas that uses silver nanoparticles. ARCI is also actively working in application development in the field of textiles.

Indian firms are also beginning to enter this area through consumer products.

TiO2-coated medical textiles

Nano based shirts

Nano clean by Luxor

Table 4.23 constructed from various websites, reports and papers highlight the main nanoproducts in the Indian domestic market or are in the advanced development stage in India.

Table 4.23: **Some visible nanotechnology based applications in different sectors**

Broad Areas	Firms/Institutions involved	Applications Developed/being Developed
Pharmaceuticals	Prakruthik Health Care	En-Tube capsules as an over the counter drug for intracorporeal detoxification
	IIT-Bombay	Nanotechnology based cardiac diagnosis product
	Shasun Pharmaceuticals and Nanoparticle Biochem	Developed NBI 129 for Prostate cancer (drug under development)
	Bilcare	Nanotechnology based anti-counterfeit technology
	Natco Pharma	Nanotechnology drug Albupax
	Richmond Chemical Corporation	Nanotech-based drug for cancer treatment
	Vascular Concepts	Combination drug eluting stent (which targets different cells at the same time)
	Dabur Pharma with Delhi University	Cancer drug Nanoxel (with nano polymer base)

Broad Areas	Firms/Institutions involved	Applications Developed/being Developed
	Concept Medical Research Private Limited (CMRPL)	'Drug delivery systems' to release drugs to block cell proliferation in the narrowed diseased coronary arteries
	University of Delhi	Non-viral carriers (Process of entrapping genetic materials in nanoparticles). Transferred technology to American Bioscience Inc.
	Lifecare Innovations	Fungisome (antifungal drug)
	Velbionanotech	Bionanochip, DNA based sensors, Ciprofloxcin, Taxol and many more medical applications
	Biocon and Abraxis BioScience	Abraxane (paclitaxel protein-bound particles for injectable suspension for the treatment of breast cancer)
	Bhaskar center for innovation and scientific research	Antimicrobial spray using silver nanoparticles and herbal extract
	Vitrus Techno Innovations	Mitsanika (gene repair therapy)
	CSIR-CSIO	Micro-diagnostic kit based on nanotechnology (for tuberculosis)
	Bharat Biotech	Estrosarb (nanoparticles loaded drug delivery systems)
	Nano Development Corporation of Houston (NDCH) and Institute of Advanced Research (IAR), India	DNA optimising and protein sequencing chip system. It comprises hardware and software elements and will be helpful in developing new drugs to prevent genetic diseases
Energy	Industrial Nanotech	Nansulate specialty coatings and energy saving technology that contains a nanotechnology based material
	United Nanotechnology and NEI Corp.	Nanotechnology based lithium ion battery electrode materials
	Mittal Enterprises	Nanofluid inferometer; Nanofluid heat capacity apparatus
	CSIR and Moser Baer	Solar photo-voltaic cell
	IIT-Delhi	Prototype automotive oil filter
	Indian Oil	Nanoparticles in lubricants and fuel to get electric, light weight, low cost and low emission vehicles

Broad Areas	Firms/Institutions involved	Applications Developed/being Developed
	CSIR-CGCRI	Novel electrode materials for high power lithium-ion battery technology (nanocrystalline LiNi Mn O - S 0.4 1.6 4d d). It has structural stability and will lead to high power batteries suitable for EV applications
	United Nanotechnology Products	Nanocrystalline Lithium iron phosphate
	ARCI	Lightening arrestor (varistor)
Biotechnology	Biomix Network (BNL)	Nanotechnology based biotechnology tools
	CSIR-NML Transferred to EUCARE Pharmaceuticals for commercialization	Sybograph (Biphasic calcium phosphate nano-bioceramic for dental and orthopaedic applications). Transferred to EUCARE Pharmaceuticals for commercialization
	CARD	Nanoblaster (blast cancer cells in the human brain)
	IIT Bombay	iSens (cantilever & molecular FET based affinity biosensor array for sensing myocardial infarction & subsequent cardiac status prognosis) Silicon-Locket (for continuous monitoring of various heart parameters)
Textiles	Bodal Chemicals	Bodactive dyes for textile industries(nanotechnology based)
	Arvind Brands in collaboration with ARCI and IIT-Delhi	Unstainable collection of shirts for men (based on nanotechnology)
	Arrow	Unstainable textiles
	Raymond	Nano treated clothing
	Mohan clothing	Nano based trousers
	Ashima	Nano treated fabric
	Bharati Walmart and Max	Nano based shirts
Consumer Products	Titan Industries (TIL)	Body wearable health care products based on micro electro mechanical systems (MEMS) technology

Broad Areas	Firms/Institutions involved	Applications Developed/being Developed
	Luxor Nano Technology	Home cleaning solutions
Water Purification	CSIR	Nanotechnology-based water filter
	ARCI, Hyderabad & SBP Aquatech	Puritech (Nanosilver coated ceramic candles)
	Tata Chemicals	Tata Swach (Effective against water borne bacteria and virus)
	Eureka Forbes and IIT-Madras	Aquaguard total water purifier (Nanotechnology solution to remove pesticides from water)
Sports	Amer Sports	Tennis and badminton rackets and golf accessories which offer higher strength, stability and power (nanotechnology based).
Miscellaneous	CSIR-NPL	Nano measeurement software (nano meteorology)
	Yashnanotech	Sensitive substrates for Raman Spectroscopy, AFM tips and metal sponges

Source: Constructed by Authors from various sources (www.nanotechproject.org; IBID database; http://www.teriin.org/nano-uploads/D5_NT_Development_in_India_Apri_2010.pdf; nanomission.gov.in and other websites like nanotech-now.com; nanowire.com; nanowerk.com)

4.5 Key Findings

The study in this chapter applies bibliometric and innovation indicators to underscore, to what extent India is making an assertion in nanoscience and nanotechnology. To have a more informed assessment, it makes a broad examination of the global scenario.

India has made significant progress in nanotechnology research. It is now the sixth most active country publishing in this field. India has shown maximum growth from year 2000 to year 2011 as compared to other advanced and emerging OECD economies. Some of the emerging economies (China, India, S. Korea and Taiwan) have also shown the increased publication share globally in later years. China's nanotechnology development provides a useful benchmark for other emerging countries to follow. China is already leading the nanotechnology publishing race (surpassed USA and other advanced OECD economies in 2009). This is a strong assertion of capability when the field is science intensive.

The analysis of highly cited papers (papers in top 1%, top 10% and papers Above World Average (AWA)) have shown that India is emerging as an important player in terms of publication output but the papers are not able to draw attention of research community to that extent. The number of papers and the share of papers globally in top 1% and top 10% cited papers from India had increased in later years. Collaboration is playing an important role in papers getting high degree of visibility (more than 50% of papers in top 1% and top 10% cited papers are collaborative). Collaboration is also playing an important role in papers getting published in high IF journals. Although China emerged as a leader in terms of number of papers but the visibility is still low as compared to other emerging and advanced OECD economies.

Research is exhibiting more interdisciplinary characteristics (reflection through journals) and activity within different subfields of nanotechnology. USA leads in publishing papers in nanotechnology in Applied Physics, Macromolecules, Physics, Chemistry and Physical Chemistry while China is a leader in other major fields, i.e. Material Science, Analytical Chemistry and Biochemistry. India's activity seems to be progressing in every area. India is building up on its strength in material science research, applied physics research and physical chemistry while addressing nanotechnology research (the areas of its strength in research). Biomedical is an active area of India in patent filing and application development but is less visible in research publications. This may be due to the interdisciplinary nature of the field nanotechnology. Significant upward trends are on account of increasing activity of institutions. COEs are playing major role in publication activity. CSIR laboratories and IIT's are the major players with maximum number of publications. Linkage analysis shows the cluster formation have strong geographical proximity. Only few firms are visible in the publication activity from India. The keyword linkage analysis shows the focus of research moving towards applied research in 2009 namely biomedical, water and environmental mitigation.

In international patent office's USA is the most prolific country in filing patents and the grant activity. China is emerging as an important player in later years. India's patenting activity is still in a nascent stage. However, some patents are promising as they address niche areas of global relevance and in addressing pressing concerns such as sensors, medicine, and water. CSIR is the major player in patent filing from India. The patents by CSIR laboratories are mainly process patents for nanoparticles, nanocrystalline compounds, nanostructures, CNTs, thin films etc., Apart from CSIR many other academic institutions are involved in patent filing activity. Industrial sector is also playing an important role in filing patent in international as well as domestic patent offices. Some of the patents filed have novel applications like DNA based arithmatics; fast reheat bottle grade polyethyleneteraphthalate resin; decontaminating water from pesticides etc.

There are some major gaps that need to be addressed in patenting. Patenting is important in this critical technology. Only a few firms and organizations from India are involved in patenting activity. This picture may change to some extent in the domestic patent office. Patenting in US provides higher value appropriation to firms particularly in a high technology area. Indications available of patenting activity in the US thus have to be seen in this context. The access of data from Indian Patent Office is not user friendly.

Standardization is very important as it defines and regulates product/process quality. India, has only taken initial first steps in addressing standardization issue. India is focusing on a few key areas for nanotechnology based intervention. Bureau of Indian Standards (BIS), CSIR-NPL and Nano Mission are the key stakeholders in the standard creation activity. So far two standards are at the test stage and two are proposed. Standardization is a major area of concern. It has not taken up to the extent it is needed to be addressed.

Nanotechnology products from India are not visible in the international market. The further examination of various sources provided more informed picture of applications in domestic market in research stage. India, although was a late starter, but has shown promise with its research and have developed few applications which can make global impact. Nano-biotechnology/Pharmaceuticals is one of the important areas now getting attention. India has developed nanotechnology based products mainly in water, medicines, computers, energy, sports, pharmaceutical/biotechnology and various consumer products. In spite of impressive research activity the translation towards product/process development needs more attention. Nanotechnology is a science intensive technology and scientific understanding is pre-requisite for developing applications in this field. This translation is possibly not happening because only a few firms are involved in research activity.

5. Discussion, Conclusions, and Strategic Priorities

5.1 Discussion

The study examines the research and innovation activity in nanotechnology with specific reference to India. For an informed understanding and benchmarking Indian activity, nanotechnology development in general and of some countries were examined in more details. The primary objective of this study was to ascertain how this key technology is evolving and to what extent India is an actor in the global arena. The efforts of Indian initiatives over a period of more than ten years were examined in terms of capacity creation and tangible outputs and outcomes.

The study highlights the different facets that make this technology the 'transformative' technology of the 21st century. It examines its potential to revolutionize a wide range of industries and provide novel innovative solutions to complex technological problems, create functional and highly differentiated products in high technologies as well as in areas that are of pressing concerns in developing and improvised economies i.e. environment, water purification, agriculture, energy and in a host of other products and services. The study underscores that some of the 'promises' are beginning to take shape with a host of novel applications/products now visible in high technologies as well as in areas of high social impact.

Some key aspects of the nanotechnology development and drivers are highlighted. For example unlike other key technologies, emerging economies have been actively involved in developing capability in this key area. Among the key factors for nanotechnology becoming an area of global research agenda, a 'priority' area of funding in different countries, has been the development of sophisticated instruments in the 1990s that allowed manipulation/engineering of matter at the atomic scale. Scientists could observe startling changes in mechanical, electrical, optical properties of different materials at the nano scale (roughly 1 to 100 nanometer, 1 nanometer equals 10^{-9} meter), which attracted global scientific, industrial and policy attention. Another key factor was the US Government placing this as a key thrust area in its research and innovation agenda. The National Nanotechnology Initiative (NNI) launched by the US Government in 2001 as a mission mode multi-agency programme was a detailed plan document providing a roadmap/vision for development of this area in different sectors with an underlying belief that this technology will create US leadership in different industries. Strongly influenced by the US strong thrust and vision in this area, different countries started dedicated programs with liberal funding support.

Competency in this area of research is an immense challenge as this is a knowledge intensive area requiring advanced R&D infrastructure, significant investment, skilled manpower having interdisciplinary competence, access to/development of sophisticated instruments, entrepreneurship and synergy among divergent set of stakeholders. Governance calls for strong linkages between decision making, planning and execution. One of the key issues in nanotechnology governance is regulation and risk mitigation which can lead to responsible technological development (address economic and social welfare without any adverse implications). Regulation which includes risk governance becomes one of the central issues as this technology has applications in diverse sectors which range from human health, food to high technology products/processes. One of the major concerns is uncertainty about the effects/potential impacts of this technology. Governance of nanotechnologies involves planning, funding prioritizing and facilitating the creation of knowledge base, developing research and innovation systems, creating supporting institutions and framework for technology regulation, skill development, IPR, risk and standards, etc. It also involves creating institutions for developing interfaces between upstream and downstream activities.

In this context, the study examined different country approaches. The examination of different country's models, policy planning and strategy 'provides' a clue to how this field is developing globally, whether it is addressing areas of high technologies and/or areas of pressing concerns, types of governance model, regulatory structure, and types of capacities created. One can discern different types of models adopted by countries learning from each other as well as distinctiveness that are influenced by their scientific capability, their inherent innovation dynamics and industrial structure. US NNI shows involvement of 25 federal agencies with wide industry representation and extensive federal budgetary support (cumulative investment is estimated to be $18 billion since NNI inception in 2001). South Korean nanotechnology programme shows a strong focus for laboratory to commercialization and promoting nanotechnology in their ICT and automotive cluster. China has undertaken a number of key policy actions to assert itself in this high technology area. Among them include focus on standard development at an early stage of their nanotechnology program initiation, development of indigenous instruments, embedding their nanotechnology centers in university science parks, attention to EHS/ELSI issues, and focus on patenting activity.

The study also found very interesting approach undertaken by countries that have limited scientific infrastructure and are in the early stages of developing innovation ecosystem. ASEAN countries belong to this group. They are funding and directing nanotechnology towards end-user applications. A few key areas have been selected based on the capability of their industry/agriculture sector. Scientific capacity for nanotechnology-based intervention is given priority in the selected industry or agriculture sector for enhancing functionality in the products/processes.

Coordinated international efforts are visible in standard development. ISO has created a specific technical committee TC 229 to cover different aspects of standardisation. Almost all the countries actively engaged in nanotechnology research are members of this committee. Countries have created their own standards and some of them are adopted by TC 229. Nanotechnology applications cover different sectors which have their own rules, regulations and acceptable norms. ISO TC 229 has complex linkages with other technical committee standards in different sectors. European Union is developing their directives for regulation and standardisation. These will have important bearing in the development of international standards.

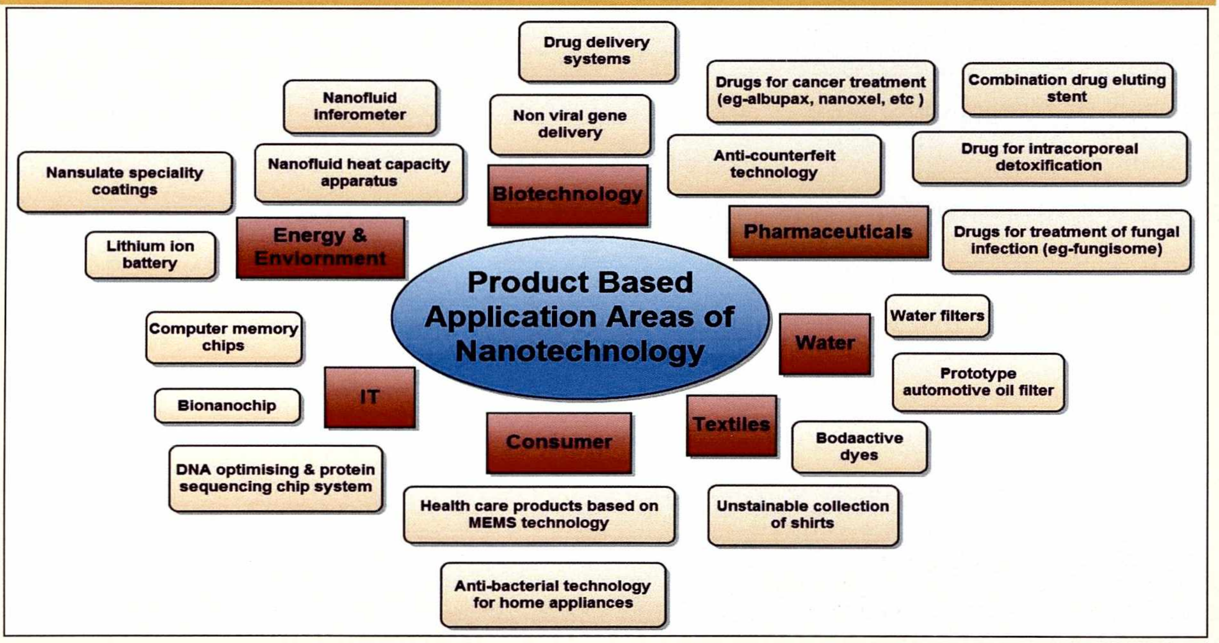
The study observes various governance approaches with government acting as the major stakeholder in all the countries. It is interesting to observe that Risk governance has been approached in different ways by countries — ranging from enforcement to participatory approaches. However, a common approach is to cover within their overall nanotechnology action plan, strategy for mitigating risk concerns. A visible strategy is towards strengthening sectoral regulations and legal provisions to accommodate perceived/visible nanotechnology risk concerns. In some of the countries, specialised institutions have been created for risk research.

The study shows that India has been able to create a nanotechnology 'research ecosystem' through the umbrella programme of NSTI followed by Nano Mission (initiated and implemented by DST) which has been complemented by multi-agency involvement (CSIR, DIT, DBT, DRDO, ISRO, etc) through their own nanotechnology programmes. They have played a major role for developing the nanotechnology research ecosystem – creation of centers of excellence, allowing researchers access to advanced instruments, funding support to universities for initialing nanotechnology courses, development of model curriculum, initiating joint university-industry projects, national workshops/conferences with strong participation of students/young scholars and foreign experts, etc.

Among the outcomes of these efforts is a vibrant nanotechnology research community exhibiting active involvement in undertaking research in different scientific domains. One of indications of their performance is the significant rise in research publications year to year. India is now (in 2011), the sixth most active country publishing in this field globally, and has shown maximum growth and increase in publication share among prolific countries. Significant upward trends are on account of increasing activity of institutions, increase in number of institutions involved in publishing, wider set of journals used for publication and increasing collaborations. Research is exhibiting more interdisciplinary characteristics (reflection through journals) and activity within different subfields of nanotechnology. India's global share and contribution among highly cited papers are increasing. Publication analysis underscores the role of collaboration. Collaboration is instrumental in increasing output, helping in publishing in high impact factor journals and in papers attracting citations.

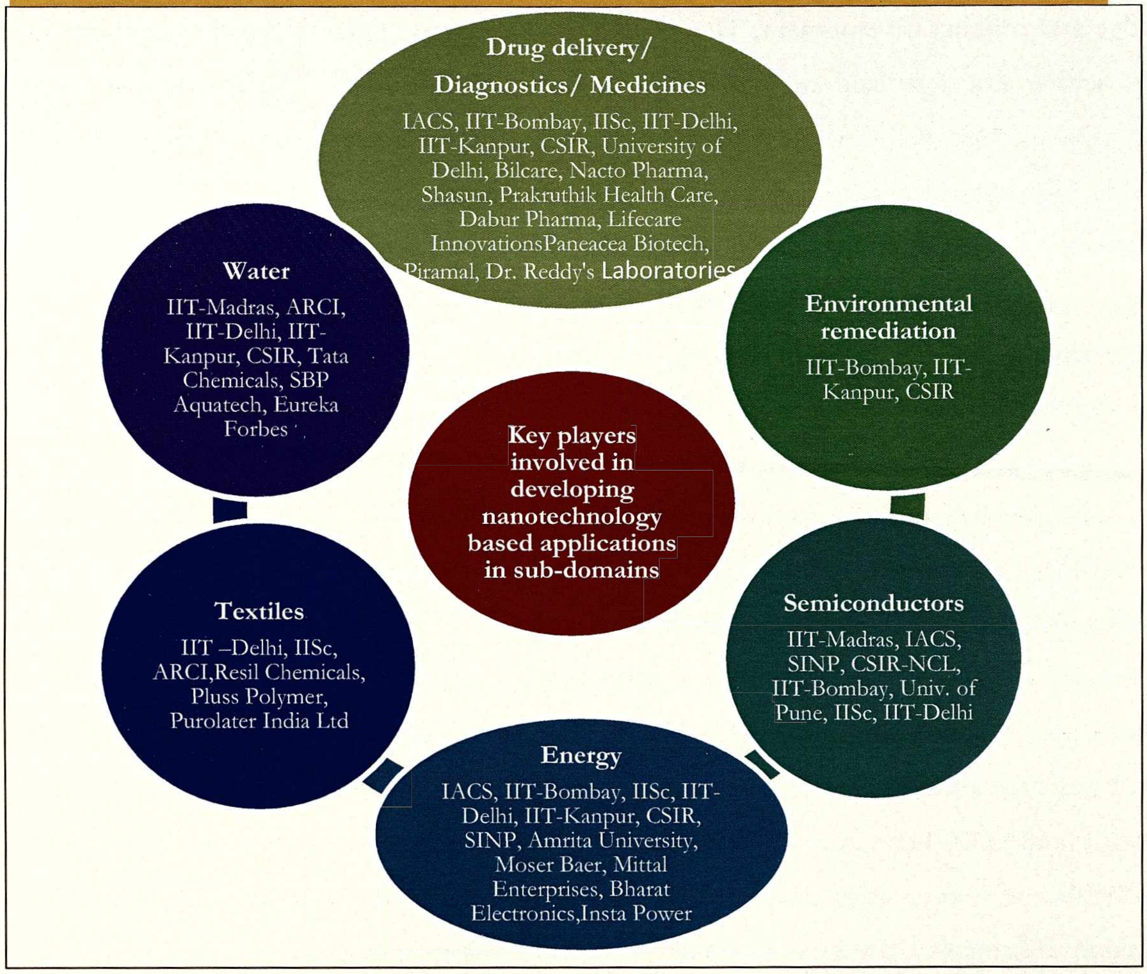
India's patenting activity is still in a nascent stage. However, some patents are promising as they address niche areas of global relevance and in addressing pressing concerns such as bio-sensors, medicine (drug delivery), and water. Standardization is very important as it defines and regulates product/process quality. India, has only taken initial first steps in addressing standardization issue. India is focusing on a few key areas for nanotechnology based intervention. Nano-biotechnology is one of the important areas now getting attention. India has developed nanotechnology based products mainly in water, medicines (primarily drug delivery), textile, and various consumer products (cleaning solutions). Figure 5.1 provides indication of the areas where nanotechnology applications are developing.

Figure 5.1: Nanotechnology based applications in different sectors –Indian Scenario



Among the encouraging developments include institutes focusing on problem areas and creation of thematic units. Figure 5.2 highlights the key players in major sub-domains.

Figure 5.2: Key players involved in sub domains of nanotechnology



The laboratory research to commercialization is a difficult process and requires more directed actions such as developing functional linkages between academia and industry. Governance mechanisms, in particular risk governance and standards development requires urgent attention. This involves anticipatory as well as participatory approach to innovation governance with the involvement of all stakeholders who influence the technology development.

5.2 Conclusion

Nanotechnology development is contingent on large number of factors such as high levels of funding support, access to sophisticated instruments, human resources capacity with specialised manpower that has the capability to work in a interdisciplinary environment, linkages with the various actors in the innovation system primarily academia-industry, institutional mechanisms that support research translation, industrial base and ability to translate R&D investments into economic outcomes, expertise in intellectual property law, regulatory framework including developing protocols for risk and life cycle assessment, political will and a conducive economic environment.

Nanotechnology is highly science intensive and calls for strong linkage with the producers of knowledge and product development. The locus of knowledge production is also required to be in multiple setting not restricted only to academia/research institutions. Firms need to develop research capability also as this would strengthen the linkages with the academia/research institutions, increase the 'absorptive' capacity of firms to new knowledge, etc.

Above conditions are not easily achievable and their existence varies from country to country. The capacities of different countries are generally assessed through their National Innovation System (NIS) framework. This framework underscores the role of various institutions for facilitating research, innovation and support system for commercialisation of ideas. The system approach which integrates institutions to create, store and transfer knowledge, skills and artefacts is the common parlance and analytical underpinning of the NIS framework. Capacity of the NIS to connect with the global knowledge network and global value chain is also an important indication of its functioning.

OECD countries have established these types of structures i.e. various institutional mechanisms to develop dynamic interfaces between various actors/stakeholders involved in knowledge creation and translation. Also various support systems for funding have been created to enable translation of laboratory research to commercialisation. A new technology particularly such as nanotechnology which is not a discreet technology or an industry sector but a range of technologies that operate at the nano-scale and is at an early stage of development, pose new set of challenges as identified and articulated in this report. Creating competency in this technology thus requires countries to develop strategies that can address the various challenges this technology possess. Countries with advanced NIS have better opportunities and advantages to develop competency then emerging and developing economies that have started engaging in nanotechnology. However, emerging economies have the advantages of learning from countries that have more developed NIS and thus not repeat the mistakes they have done, can overcome the lock-in effect, etc. Entering in a new technology can thus provide opportunities for emerging economies unlike established technologies where space for entry is limited as knowledge monopoly is extensive and market access has high entry barriers.

Nanotechnology is a science intensive interdisciplinary field and calls for highly skilled manpower, sophisticated instruments, cross-disciplinary research focus and functional linkages between academia-industry among others for translating promises into desired economic and/or social outcomes. Capital intensive nature of this technology, technological uncertainty, developing the knowledge base among others has made Government the major stakeholder in nanotechnology development in different countries. Long term plans with significant funding support is visible in countries actively engaged in this field. Wide dispersion of research activity is observed globally in nanotechnology unlike other cutting edge science based technological fields. Among others the early involvement of emerging economies may be due to myriads of sectors where nanotechnology can make significant economic and/or social impact including providing solutions to issues of pressing developmental concerns.

India's present status of nanotechnology is still not in the league of countries such as US, Japan, South Korea, Germany, and China. However, it has developed a strong research ecosystem in this field with dedicated research groups in universities/research institutes. One of the key features that draw attention is its strong focus on creating nano-based applications in areas of pressing concerns namely effective drug delivery, safe drinking water, and energy.

Nanotechnology is making interventions in major sectors globally. Advanced OECD countries show strong focus on ICT enabled applications. Renewable energy particularly 'solar energy' is an active area of nanotechnology research. Emerging countries like India are demonstrating new pathways for addressing pressing problems of 'water', effective drug delivery through nanotechnology interventions. Countries scientific capacity, its innovation ecosystem and industrial structure has strong bearing on individual country approach. Advanced countries are trying to get first mover advantage that would allow them to control and define leadership in this key technology. However, they face strong challenge from South Korea and China.

China and India have many similarities with other countries in transition that are trying to create an 'innovation climate' that would help them to move closer to frontier technologies and 'catch up' (defined in terms of production to innovation capabilities) with OECD economies. Nanotechnology provides opportunity for both these countries to make this transition. China is already emerging as one of the major player in nanotechnology. It has created institutions that are supporting university-industry linkages and have strategic plan for nanotechnology intervention in key sectors.

ASEAN countries approach is pragmatic; within its small scientific ecosystem it is undertaking research in this field. The strategic plan is to enable their industry/agriculture sector to enhance competitiveness and social impact through undertaking applied nanotechnology research. Two distinct models can be discerned from examination of nanotechnology developed in some countries actively involved in this field. Countries with advanced scientific capacity and highly efficient innovation ecosystem are working in the different domains of nanotechnology; applying nanotechnology to enhance competitiveness in different manufacturing sectors. Emerging countries such as BRICS countries are also following this approach to some extent. On the other hand countries such as Sri Lanka, ASEAN countries with more constrained resources/scientific diversity are focusing on end user applications. It is important to learn from these countries also as they have well directed and targeted approach.

5.3 Strategic Priorities

India's papers are attracting attention but still large numbers of papers remains uncited or attract one/two citations. The ratio of citation per paper is still very low, an indication of weak reception. Patenting is important in this critical technology. Only a few firms and organizations from India are involved in patenting activity.

Inspite of impressive research activity the translation towards product/process development needs more attention. Nanotechnology is a science intensive technology and scientific understanding is pre-requisite for developing applications in this field. This translation is possibly not happening because only a few firms are involved in research activity. Standardization is a major area of concern. It has not taken up to the extent it is needed to be addressed.

Industry is demanding approved testing facilities, regulatory framework to be strengthened that facilities their development process. Standard development is still at a preliminary stage which needs more attention. There is a need for creation of bridging institutions/mechanisms that support translational research. Venture capital fund and other funding mechanisms that provide support for the whole innovation value chain and laboratory to market (support to entrepreneurs to establish and validate proof-of-concept, enable creation of spin-offs etc).

Nanotechnology as a priority area of research was articulated more or less at the same time when other countries started their programs influenced by US National nanotechnology Initiative. Comparison of India's progress with other countries brings to focus the major gaps that need to be addressed. China's nanotechnology development provides a useful benchmark for other emerging countries to follow. China is already leading the nanotechnology publishing race. This is a strong assertion of capability when the field is science intensive. China's patenting activity was negligible earlier but has shown significant progress. This can be seen for application filled in the U.S. patent office (USPTO). It also highlights the academia-industry linkages. China in 2005 became the first country to issue national standards for nanotechnology. China's active involvement in standard creation and adoption is its overreaching strategy for future technology domination in this critical field. China's nanotechnology products are visible in international markets.

Examination of China's nanotechnology development shows that with strong strategic focus, it is possible to emerge as a leading country in a frontier area of research. India needs to become more aggressive like China to make its presence more strong in the international stage. Stakes are high as estimated market value and economic and social benefits are immense for countries that can attain competency in this technology. Nanotechnology provides opportunity for countries like India to move up the value chain.

Different countries model highlights the need for long term strategic goal for achieving convergence with advanced OECD economies in a frontier technology. Research institutes/ universities, industry and policy partners have to develop strategic relationships. Along with building basic research capability, promotion of innovative start-ups and technology transfer from academia to industry through various institutional mechanisms such as science parks, incubation centers, and industrial high technology zones drives laboratory to commercialization. Education and skill development requires strong government support and planning.

However, one also has to be cautious in adopting a similar strategy like that of China. Programs they have articulated are ambitious and can lead to lock-up of resources without significant tangible benefits.

An area which requires more funding is research on toxicity, exposure, hazards of various nano components in order to create an 'early warning' system. The various centre of excellence in India can have important role in taking initiative in this direction. 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. 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.

There is a gap in understanding of the impact of nanoparticles on the human body. More directed approach would be required to increase research in this area. Focus on regulatory issues- industry bodies and academia can help promote new initiatives. Standard development- needs to be undertaken aggressively. Sector based efforts for standardization is required and should be linked with international efforts. As nanotechnology has applications in different areas and would thus require a more dispersed approach.

China's and other emerging economies success in high technologies are also a signal for advanced OECD economies as they have now new players to challenge their high technology dominance. This can be an important lesson for emerging countries like India, Brazil that are also trying to create an innovation ecosystem. Nanotechnology governance in India has been successful to the extent of creating an active research network, common sharing of facilities, and supporting researchers through various funding schemes. *The study posits that the following strategies/actions can make the nanotechnology program to achieve the objective of creating a research and innovation ecosystem that can lead to development of applications covering economic and social benefits.*

Strategic Priority 1

Nanotechnology in India has evolved as a multi-agency program with involvement of different government agencies providing support for capacity building and sectoral intervention. ***The study recommends creation of an empowered structure that can coordinate investment in research and development (R&D) activities in nanoscience and technology.*** This will create horizontal linkages among different agencies which among others help in coordinated approach to key elements for nanotechnology development such as human resource development, regulation, capacity building, etc.

Strategic Priority 2

Developing skilled human resource in this area is challenging as it calls for interdisciplinary competency along with grounding in natural science/engineering. ***The study recommends (a) Creation of interdisciplinary courses and separate program in nanotechnology at post-graduate level that meets the requirement of industry at large (b) Creation of advanced certification/diploma in nanotechnology for imparting students various skills (handling advanced instruments, patenting aspects, etc) and industrial exposure.***

Strategic Priority 3

The study shows that well defined mission program and involvement of various scientific agencies has led to the creation of 'research ecosystem'. ***The study recommends that in the next phase it is important to develop a Roadmap/Framework that helps progression from 'research ecosystem' towards an 'innovation ecosystem' and commercialization.***

The roadmap should have a balanced approach: along with strengthening discipline based objectives it should also give emphasis to social needs. It needs to create opportunities for different stakeholders and should have short, medium and long term perspective. For example, short term perspective need to pay attention for exploiting existing knowledge. More focus would be towards development and creating interface mechanisms for scaling up the technology, industry partnership, etc. Medium and particularly long terms perspective would incorporate strategies of short term but also need to place sufficient resources for creation of knowledge, develop governance framework, regulation, etc.

The Roadmap should also give due emphasis for strengthening collaboration/strategic partnerships between academia and industry. Institutional support mechanisms such as Centers of Excellence and Nanotechnology Centers that have been created can act as bridges for developing linkages, creating partnerships in the whole value chain of technology development i.e. from research to innovation and product design. The centers needs to be augmented with different support systems therein such as technology transfer office, patent examination and filing facility, incubation and proof of concept funding, state of art search for assessing current developments, etc. These centers should help in bridging fundamental science and real world applications in different sectors.

Nanotechnology has multiple applications in myriads of sectors. Each sector has its own distinctiveness, inherent dynamism, concerns which needs to be addressed for responsible intervention of nanotechnologies in that sector. Sectoral concerns should be taken into account in the Roadmap.

Strategic Priority 4

Nanotechnology development is to a very large extent contingent on access to sophisticated instruments. ***The study recommends dedicated instrumentation program for developing sophisticated instruments.*** The program should be backed by specific policy articulation with long term dedicated funding and with the involvement of academia and industry. This includes developing international collaborations for joint instrumentation development.

For increasing access to sophisticated instruments; existing programs like INUP should be strengthened further by creating more nodal points; access to international facilities such as European Synchrotron Radiation Facility (ESRF), beam lines, etc.

Strategic Priority 5

The questions of nanotechnology definition and classification, examination, international rules, etc are key concerns in patenting and standardisation. Institutions engaged in nanotechnology research should have more horizontal linkages with patent office, and standard development institutions. ***The study recommends development of a centre of excellence to examine patenting (patent guidelines in this area, facilitating the patenting process, etc) and other IPR issues, develop***

linkages between academia and patent office, create joint mechanisms for developing sector specific standards, etc.

Strategic Priority 6

Governance mechanism including regulation and risk mitigation requires urgent attention. ***The study recommends dedicated funding support for EHS/ELSI including creation of a coordinating centre for regulation and risk research.*** The centre needs to address the aforesaid issues in the whole value chain of a product/process development. Regulatory and risk aspects should focus on each sector and take in account the sector specific peculiarities and challenges.

Strategic Priority 7

Assessment exercise are very important to gauge the status of the various programs i.e. to what extent they are addressing the objectives; whether the programmes properly address the contemporary and emerging trends, new directions to strengthen the programs, etc. ***The study recommends continuous monitoring and periodic detailed assessment of research and innovation capacity, outcomes and outputs, shortcomings and new opportunities.***

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Annexure

Annexure I: Quarry Terms

Annexure I a: Search strategy Kostoff *et al.* (2006)

(atomic same force same microscope) or (transmission same electron same microscope) or (scanning same tunnling same microscope) or (quantum same dot) or (quantum same wire) or (self-assemble same monolayer) or (self-assemble same film) or (self-assemble same layer) or (self-assemble same multilayer) or (self-assemble same array) or nanoelectrospray or (coulomb same blockade) or (molecular same wire) And (nanoparticle* or nanotub* or nanostructure* or nanocomposite* or nanowire* or nanocrystal* or nanofiber* or nanosphere* or nanorod* or nanotechnolog* or nanocluster* or nanocapsule* or nanomaterial* or nanophase* or nanopowder* or nanolithography* or nanodevice* or nanodot* or nanoindent* or nanolayer* or nanoscience* or nanosize* or nanoscale* or nanometer* or nanosurface* or nanofilm* or nanograin* or nanosilicon* or nanodeposition*)

Annexure I b: Search strategy Mogoutov and Kahane (2007)

Subfield	Query
Physics	(TS=("walled carbon") OR TS=("metallic carbon") OR TS=("semiconducting carbon") OR TS=("carbon tube*") OR TS=("mechanical resonator*") OR TS=("quantum dot*") OR TS=("single carbon") OR TS=("surface plasmon") OR TS=("low dimensional system*") OR TS=("semiconductor structure*") OR TS="atomistic simulation" OR TS="finite-difference time-domain method" OR TS="chemisorption"
Physical Chemistry	OR TS=("walled carbon") OR TS=("carbon tube*") OR TS=("tio2 solar") OR TS=("sensitized tio2") OR TS=("sensitized solar") OR TS=("tio2 films") OR TS=("dye tio2") OR TS=("li batter*") OR TS=("dye solar") OR TS=("single carbon") OR TS=("solar cell*") OR TS=("electrochemical performance") OR TS="carbon composite*" OR TS="carbon fiber*"
Applied Physics	OR TS=("induced deposition") OR TS=("field emitter*") OR TS=("field emission") OR TS=("crystal* memory") OR TS=("crystalline diamond") OR TS=("emission propert*") OR TS=("vapor deposition") OR TS=("chemical vapor") OR TS=("plasma chemical") OR TS=("carbon film*") OR TS=("magnetic fluid") OR TS=("ion implantation") OR TS=("thin film*") OR TS=("laser ablation") OR TS=("crystalline silicon") OR TS=("film* deposit*")

	OR TS=("laser deposition") OR TS=("beam epitaxy") OR TS="crystal morphology" OR TS="sputtering" OR TS="molecular beam epitaxy"
Biochemistry	OR TS=("solid lipid") OR TS=("gold particle*") OR TS=("plga particle*") OR TS=("gold catalyst*") OR TS=("mesoporous silica") OR TS=("co oxidation") OR TS=("drug carrier")
Chemistry	OR TS=("enhanced raman") OR TS=("gold particle*")) OR (TS=("direct electrochemistry") OR TS=("tube* modified") OR TS=("electrode modified") OR TS=("resonance light") OR TS=("immunosensor based") OR TS=("glucose biosensor") OR TS=("modified glassy") OR TS=("raman scattering") OR TS=("modified electrode") OR TS=("biosensor based") OR TS=("electrochemical biosensor") TS=("drug delivery") OR TS=("heterogeneous catalyst*") OR TS=("drug release") OR TS=("lipid particle*") OR TS=("delivery system") OR TS="surface chemistry" OR TS="drug delivery" OR TS="heterogeneous catalysis" OR TS="supramolecular chemistry" OR TS="gene delivery"
Analytical Chemistry	OR TS=("ball milling") OR TS=("composite powder*") OR TS=("severe plastic") OR TS=("gel method") OR TS=("tribological propert*") OR TS=("amorphous alloy") OR TS=("plasma sintering") OR TS=("mechanical alloy") OR TS=("spark plasma") OR TS=("composite* coating*") OR TS=("composite coating*") OR TS=("metallic glass") OR TS=("gold electrode") OR TS=("carbon electrode") OR TS="biosensor" OR TS="single-molecule"
Material Science	OR TS=("silicate composite*") OR TS=("clay composite*") OR TS=("/clay composite*") OR TS=("oligomeric silsesquioxane") OR TS=("situ polymerization") OR TS=("poly methacrylate") OR TS=("block copolymer") OR TS=("polymer composite*") OR TS=("composite* prepared")) OR TS=("coating* deposited") OR TS=("al2o3 composite*") OR TS=("coating* produced") OR TS=("grain growth") OR TS=("plastic deformation") OR TS=("microstructural evolution") OR TS=("sol* method*") OR TS="hydrogen storage material*" OR TS="sintering" OR TS="microstructure" OR TS="superplasticity" OR
Macromolecules	(TS=("surface plasmons") OR TS=("electrostatic force microscopy") OR TS=("quantum rings") OR TS=("chemical vapor deposition") OR TS=("transmission electron microscopy") OR TS=("graphitic carbon") OR TS=("dye-sensitized solar cell") OR TS=("porous carbon") OR TS=("supercapacitor") OR TS=("growth from solutions") OR TS=("semiconducting material*") OR TS=("magnetization reversal") OR TS=("zinc compound*") OR TS=("diamond film*") OR TS=("diamond-like carbon") OR TS=("soft magnetic material*") OR TS=("primordial protein*") OR TS=("mesoporous material*") OR TS=("self-assembly") OR TS=("mesoporous") OR TS=("surface-enhanced Raman") OR

	TS=("mechanical alloying") OR TS=("spark plasma sintering") OR TS=("ball milling") OR TS=("montmorillonite") OR TS=("organoclay") OR TS=("electrospinning") OR TS=("block copolymer*"))

Annexure II: Data of Figures in the Report

Annexure II a: Publication activity of key advanced OECD and emerging economies

	China	USA	Japan	Germany	France	India	Brazil	South Korea	Taiwan	England
2000	1752	3838	2034	1672	947	336	191	459	225	804
2001	2186	4242	2305	1717	989	390	199	629	316	790
2002	3020	5286	2516	1992	1157	547	279	825	430	983
2003	4100	6521	3181	2306	1356	713	314	1212	589	1042
2004	5397	7031	3356	2351	1432	891	327	1398	782	1119
2005	7672	9567	4020	3033	2044	1185	464	1968	1221	1479
2006	8936	10240	3904	3242	2055	1508	511	2201	1466	1610
2007	10715	10801	4189	3377	2244	1917	599	2476	1610	1827
2008	13872	12987	4743	4225	2896	2664	775	3326	1888	2217
2009	15961	13728	5095	4590	3229	3217	891	3972	2310	2523
2010	17532	16783	5206	5270	3423	3824	1014	4608	2472	2723
2011	22132	17288	5382	5430	3677	5020	1046	5344	2792	2736

Annexure II b: Emerging Asian countries making progress in nanotechnology

	India	Malaysia	Thailand	Iran	Sri Lanka	Singapore
2000	336	4	3	1	1	150
2001	390	5	10	4	6	173
2002	547	13	11	9	5	222
2003	713	12	17	9	8	270
2004	891	41	31	31	12	468
2005	1185	36	81	82	13	598
2006	1508	79	127	199	12	745
2007	1917	82	209	417	14	841
2008	2664	165	348	728	14	1011
2009	3217	302	285	1202	8	1077
2010	3824	404	398	1756	10	1363
2011	5020	724	421	2684	15	1536

Annexure II c: Publication share in nanotechnology

	China	USA	Japan	Germany	France	India	Brazil	South Korea	Taiwan	England
2000	12.6	27.7	14.7	12.1	6.8	2.4	1.4	3.3	1.6	5.8
2001	12.8	24.8	13.4	10.0	5.8	2.3	1.2	3.7	1.8	4.6
2002	14.6	25.5	12.2	9.6	5.6	2.6	1.3	4.0	2.1	4.7
2003	15.5	24.7	12.0	8.7	5.1	2.7	1.2	4.6	2.2	3.9
2004	16.6	21.6	10.3	7.2	4.4	2.7	1.0	4.3	2.4	3.4
2005	19.5	24.3	10.2	7.7	5.2	3.0	1.2	5.0	3.1	3.8
2006	19.2	21.9	8.4	6.9	4.4	3.2	1.1	4.7	3.1	3.5
2007	19.4	19.6	7.6	6.1	4.1	3.5	1.1	4.5	2.9	3.3
2008	22.1	20.7	7.6	6.7	4.6	4.2	1.2	5.3	3.0	3.5
2009	23.3	20.1	7.5	6.7	4.7	4.7	1.3	5.8	3.4	3.7
2010	23.6	22.6	7.0	7.1	4.6	5.1	1.4	6.2	3.3	3.7
2011	26.4	20.6	6.4	6.5	4.4	6.0	1.2	6.4	3.3	3.3

Annexure II d: Linkages among institutions in the top 1% cited papers (2009)

Publication Title	Authors name	Institution
Graphene: The New Two-Dimensional Nanomaterial	Rao CNR, Sood AK, Subrahmanyam KS, et al	International Centre for Materials Science, New Chemistry Unit and CSIR Centre of Excellence in Chemistry, Jawaharlal Nehru Centre for Advanced Scientific Research,Department of Physics, Indian Institute of Science
Silver nanoparticles as a new generation of antimicrobials	Rai M, Yadav A, Gade A	SGB Amravati Univ, Dept Biotechnol, Amravati University
Graphene, the new nanocarbon	Rao CNR, Biswas K, Subrahmanyam KS, et al	Jawaharlal Nehru Ctr Adv Sci Res, Chem & Phys Mat Unit, New Chem Unit, DST Unit Nanosci, Bangalore,Indian Inst Sci, Solid State & Struct Chem Unit, Bangalore,CSIR Ctr Excellence Chem, Bangalore
Simple Method of Preparing Graphene Flakes by an Arc-Discharge Method	Subrahmanyam KS, Panchakarla LS, Govindaraj A, et al	Jawaharlal Nehru Ctr Adv Sci Res, Chem & Phys Mat Unit, Bangalore,CSIR Ctr Excellence Chem, Bangalore,Indian Inst Sci, Solid State & Struct Chem Unit, Bangalore

Ferromagnetism as a universal feature of inorganic nanoparticles	Sundaresan A, Rao CNR	Jawaharlal Nehru Ctr Adv Sci Res, Chem & Phys Mat Unit, Bangalore,
Perspectives for chitosan based antimicrobial films in food applications	Dutta PK, Tripathi S, Mehrotra GK, et al	Jawaharlal Nehru Ctr Adv Sci Res, Chem & Phys Mat Unit, Bangalore,Reliance Life Sci Pvt Ltd, Regenerat Med, Rabale
CuO Nanoparticles Catalyzed C-N, C-O, and C-S Cross-Coupling Reactions: Scope and Mechanism	Jammi S, Sakthivel S, Rout L, et al	Indian Inst Technol Guwahati
Computationally Guided Photothermal Tumor Therapy Using Long-Circulating Gold Nanorod Antennas	von Maltzahn G, Park JH, Agrawal A, et al	Brigham & Womens Hosp, MIT, Boston,Brigham & Womens Hosp, Howard Hughes Med Inst, Boston,Harvard MIT Div Hlth Sci & Technol, Cambridge,Indian Inst Technol, Dept Mech Engn, Madras
Progress in preparation, processing and applications of polyaniline	Bhadra S, Khastgir D, Singha NK, et al	Indian Inst Technol, Ctr Rubber Technol, Kharagpur , Chonbuk Natl Univ, BIN Fus Res Team, Dept Polymer & Nanoengn, Jeonju
Lipid-based systemic delivery of siRNA	Tseng YC, Mozumdar S, Huang L	Univ N Carolina, Sch Pharm, Div Mol Pharmaceut, Chapel Hill, Univ Delhi, Dept Chem, Delhi
Nano Indium Oxide as a Recyclable Catalyst for C-S Cross-Coupling of Thiols with Aryl Halides under Ligand Free conditions	Reddy VP, Kumar AV, Swapna K, et al	Indian Inst Chem Technol, Organ Chem Div 1, Hyderabad
Chitin and chitosan polymers: Chemistry, solubility and fiber formation	Pillai CKS, Paul W, Sharma CP	Sree Chitra Tirunal Inst Med Sci & Technol, Biomed Technol Wing, Div Biosurface Technol, Thiruvananthapuram
Role of defects in tailoring structural, electrical and optical properties of ZnO	Dutta S, Chattopadhyay S, Sarkar A, et al	Univ Calcutta, Dept Phys, Calcutta,Taki Govt Coll, Dept Phys, Taki ,Bangabasi Morning Coll, Dept Phys, Calcutta,VECC, Calcutta
Solvothermal Synthesis, Cathodoluminescence, and Field-Emission Properties of Pure and N-Doped ZnO Nanobullets	Gautam UK, Panchakarla LS, Dierre B, et al	Natl Inst Mat Sci, ICYS, Tsukuba, Ibaraki, Natl Inst Mat Sci, Nanoscale Mat Ctr, World Premier Int Ctr Mat Nanoarchitecton, Tsukuba, Ibaraki, Jawaharlal Nehru Ctr Adv Sci Res, Chem & Phys Mat Unit, DST Unit Nanosci, Bangalore ,CSIR Ctr Excellence Chem, Bangalore

Synthesis, Structure, and Properties of Boron- and Nitrogen-Doped Graphene	Panchokarla LS, Subrahmanyam KS, Saha SK, et al	Jawaharlal Nehru Ctr Adv Sci Res, Theoret Sci Unit, Bangalore, Int Ctr Mat Sci, Chem & Phys Mat Unit, New Chem Unit, Bangalore ,CSIR, Ctr Excellence Chem, Bangalore
A DNA nanomachine that maps spatial and temporal pH changes inside living cells	Modi S, Swetha MG, Goswami D, et al.	Natl Ctr Biol Sci, Tata Inst Fundamental Res, GKVK, Bangalore
Nanoparticle encapsulation improves oral bioavailability of curcumin by at least 9-fold when compared to curcumin administered with piperine as absorption enhancer	Shaikh J, Ankola DD, Beniwal V, et al	Univ Strathclyde, Strathclyde Inst Pharm & Biomed Sci, Glasgow, NIPER, Dept Pharmaceut, Sas Nagar
Binding of DNA Nucleobases and Nucleosides with Graphene	Varghese N, Mogera U, Govindaraj A, et al	Jawaharlal Nehru Ctr Adv Sci Res, Chem & Phys Mat Unit, DST Nanosci Unit, Bangalore ,CSIR Ctr Excellence Chem, Bangalore ,Indian Inst Sci, Dept Phys, Bangalore
Supramolecular gels 'in action'	Banerjee S, Das RK, Maitra U	Indian Inst Sci, Dept Organ Chem, Bangalore
Recent advances in material science for developing enzyme electrodes	Sarma AK, Vatsyayan P, Goswami P, et al	Indian Inst Technol Guwahati, Dept Biotechnol, Gauhati ,St Louis Univ, Dept Chem, St Louis, MO
Selective Zinc(II)-Ion Fluorescence Sensing by a Functionalized Mesoporous Material Covalently Grafted with a Fluorescent Chromophore and Consequent Biological Applications	Sarkar K, Dhara K, Nandi M, et al	Indian Assoc Cultivat Sci, Dept Mat Sci, Calcutta
Biological synthesis of silver and gold nanoparticles using apiin as reducing agent	Kasthuri J, Veerapandian S, Rajendiran N	Univ Madras, Dept Polymer Sci, Madras ,SRM Univ, Dept Chem, Fac Engn & Technol, Madras
Nickel nanoparticle-catalyzed facile and efficient one-pot synthesis of polyhydroquinoline derivatives via Hantzsch condensation under solvent-free conditions	Sapkal SB, Shelke KF, Shingate BB, et al	Dr Babasaheb Ambedkar Marathwada Univ, Dept Chem, Aurangabad
Nanoscale particles for polymer degradation and stabilization-Trends and future perspectives	Kumar AP, Depan D, Tomer NS, et al	Natl Chem Lab, Polymer Sci & Engn Div, Pune ,Clemson Univ, Dept Chem & Biomol Engn, Clemson, SC

Aerobic ligand-free Suzuki coupling catalyzed by in situ-generated palladium nanoparticles in water	Saha D, Chattopadhyay K, Ranu BC	Indian Assoc Cultivat Sci, Dept Organ Chem, Calcutta
Copper Oxide Nanoparticle-Catalyzed Coupling of Diaryl Diselenide with Aryl Halides under Ligand-Free Conditions	Reddy VP, Kumar AV, Swapna K, et al	Indian Inst Chem Technol, Organ Chem Div 1, Hyderabad

Annexure III: Sub-classifications of Nanotechnology in the USPTO and the EPO

Annexure III a: USPTO sub-classification for nanotechnology (class 977)

700 NANOSTRUCTURE
701 Integrated with dissimilar structures on a common substrate
724 Devices having flexible or movable element
734 Fullerenes (i.e., graphene-based structures, such as nanohorns, nanococoons, anoscrolls, etc.) or fullerene-like structures (e.g., WS2 or MoS2 chalcogenide nanotubes, planar C3N4, etc.)
754 Dendrimer (i.e., serially branching or "tree-like" structure)
755 Nanosheet or quantum barrier/well (i.e., layer structure having one dimension or thickness of 100 nm or less)
756 Lipid layer
762 Nanowire or quantum wire (axially elongated structure having two dimensions of 100 nm or less)
773 Nanoparticle (structure having three dimensions of 100 nm or less)
778 Within specified host or matrix material (e.g., nanocomposite films, etc.)
788 Of specified organic or carbonbased composition
810 Of specified metal or metal alloy composition
811 Of specified metal oxide composition (e.g., conducting or semiconducting compositions such as ITO, ZnOx, etc.)
813 Of specified inorganic semiconductor composition (e.g., periodic table group IV-VI compositions, etc.
827 Formed from hybrid organic/inorganic semiconductor compositions
831 Of specified ceramic or electrically insulating compositions

832 Having specified property (e.g., lattice-constant, thermal expansion coefficient, etc.)
839 MATHEMATICAL ALGORITHMS, E.G., COMPUTER SOFTWARE, ETC., SPECIFICALLY ADAPTED FOR MODELING CONFIGURATIONS OR PROPERTIES OF NANOSTRUCTURE
840 MANUFACTURE, TREATMENT, OR DETECTION OF NANOSTRUCTURE
841 Environmental containment or disposal of nanostructure material
842 For carbon nanotubes or fullerenes
849 With scanning probe
880 With arrangement, process, or apparatus for testing
882 Assembling of separate components (e.g., by attaching, etc.)
887 Nanoimprint lithography (i.e., nanostamp)
888 Shaping or removal of materials (e.g., etching, etc.)
890 Deposition of materials (e.g., coating, CVD, or ALD, etc.)
894 Having step or means utilizing biological growth
895 Having step or means utilizing chemical property
900 Having step or means utilizing mechanical or thermal property (e.g., pressure, heat, etc.)
901 Having step or means utilizing electromagnetic property (e.g., optical, x-ray, electron beam, etc.)
902 SPECIFIED USE OF NANOSTRUCTURE
903 For conversion, containment, or destruction of hazardous material
904 For medical, immunological, body treatment, or diagnosis
932 For electronic or optoelectronic` application:
961 For textile or fabric treatment:
962 For carrying or transporting:
963 MISCELLANEOUS

Annexure III b: EPO sub-classification for nanotechnology (class B82)

B82	**NANO-TECHNOLOGY**
B82B	**NANO-STRUCTURES FORMED BY MANIPULATION OF INDIVIDUAL ATOMS, MOLECULES, OR LIMITED COLLECTIONS OF ATOMS OR MOLECULES AS DISCRETE UNITS; MANUFACTURE OR TREATMENT THEREOF**
B82B1	Nano-structures formed by manipulation of individual atoms or molecules, or limited collections of atoms or molecules as discrete units [N9803] [C1012]
B82B3	Manufacture or treatment of nano-structures by manipulation of individual atoms or molecules, or limited collections of atoms or molecules as discrete units [N9803] [C1012]
B82Y	**SPECIFIC USES OR APPLICATIONS OF NANO-STRUCTURES; MEASUREMENT OR ANALYSIS OF NANO-STRUCTURES; MANUFACTURE OR TREATMENT OF NANO-STRUCTURES**
B82Y5	Nano-biotechnology or nano-medicine, e.g. protein engineering or drug delivery [N1012]
B82Y10	Nano-technology for information processing, storage or transmission, e.g. quantum computing or single electron logic[N1012]
B82Y15	Nano-technology for interacting, sensing or actuating, e.g. quantum dots as markers in protein assays or molecular motors [N1012]
B82Y20	Nano-optics, e.g. quantum optics or photonic crystals [N1012]
B82Y25	Nano-magnetism, e.g. magnetoimpedance, anisotropic magnetoresistance, giant magnetoresistance or tunneling magnetoresistance [N1012]
B82Y30	Nano-technology for materials or surface science, e.g. nano-composites [N1012]
B82Y35	Methods or apparatus for measurement or analysis of nano-structures [N1012]
B82Y40	Manufacture or treatment of nano-structures [N1012]
B82Y99	Subject matter not provided for in other groups of this subclass [N1012]

Brief Profile of the Contributors

Dr. Sujit Bhattacharya is MSc (Physics) from Delhi University and PhD (IIT-Delhi). He is a Senior Principal Scientist in CSIR-NISTADS, New Delhi and Editor-In-Chief of the 'Journal of Scientometric Research'. He works in the area of 'Science, Technology and Innovation Policy Studies', Scientometrics, and Intellectual Property Rights. He has published widely in the aforesaid areas.

Jayanthi A. Pushkaran was Senior Project Fellow at CSIR-NISTADS during the period 2011-2012, attached to this project. She is a PhD Scholar at the Centre for Studies in Science Policy, Jawaharlal Nehru University. She is especially interested in risk and governance issues in emerging technologies and is contributing actively in this theme.

Shilpa was a Project Assistant at CSIR-NISTADS during the period 2011-2012, attached to this project. She is M.Sc in Bioinformatics and is developing competency in data mining and visualization which is reflected in her research contributions

Madhulika Bhati is a scientist at NISTADS. She did her PhD from Forest Research Institute, Dehradun. Her areas of interest are green technologies, nanotechnology standard development and technology policy and innovation.

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About the Report

In the last decade or so nanotechnology became one of the high priority areas of funding in advanced as well as emerging economies primarily due to the 'promise' this technology demonstrated; of providing solutions in high technologies and also possibility of new pathways for mitigating pressing developmental issues. India like other emerging economies is looking upon this technology as a 'window of opportunity' that would help them to leapfrog the 'catch up' process and address issues of pressing concerns. This has led to various initiatives taken by Indian Government to create capacity with directed goals.

The study makes an assessment at this stage; a decade after the government started funding nanotechnology. The study shows that initial problematic surrounding capacity creation has been addressed to some extent. Scientific publications in particular have shown significant progress. India's application development looks promising as it shows it is addressing areas of pressing concerns like water, energy, medicine. However, it is too early to say whether India's research outputs can translate to niche global products or can make a major impact in Indian industry and society. Based on this assessment strategic priorities are articulated that the study posits can help create a nanotechnology innovation ecosystem, develop strong functional linkages with different stakeholders, create institutions that can address governance challenges and establish innovation chain from laboratory to market.

CSIR-NISTADS

CSIR-National Institute of Science, Technology and Development Studies (CSIR-NISTADS) is one of the leading institutions under CSIR exploring interface between science, technology, and society. The institute as a knowledge-generating organization carries out studies in several areas of national importance, for example, S&T policy, innovation, & national competitiveness in global context, CSIR & public funded knowledge & technology, mapping knowledge trends and outcomes in S&T. It also undertakes studies on history & philosophy of sciences and technology (S&T), and S&T for weaker sections.

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