Nanotechnology development in India: the need for building capability and governing the technology

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This briefing paper summarizes the key findings of TERI's ongoing project, 'Capability, Governance and Nanotechnology Developments: A Focus on India'. This a three year research (April 2007–March 2010), which, through a focus on India, examines various aspects of developing country capability needed to (i) respond to Nanotechnology (NT) challenges, (ii) engage with NT developments and debates, and (iii) help establish an innovative governance framework. The research has two components: a global and an Indian case study component. These are linked as information and analysis of global developments inform the case study and the insights from the case study help inform the global debate. The research approach combines two bodies of work – science and technology studies with development studies.

The final report will be available in April 2010.

For further details and working papers, please visit the project web page
http://www.teriin.org/index.php?option=com_ongoing&task=details&sid=675&theme=

Table of Contents

Nanotechnology development in India: the need for building capability and governing the technology

Key Points

- Nanotechnology today is regarded as a revolutionary technology that can help address key needs relating to energy, environment, health and agriculture in developing countries.
- Nanotechnology development in the forerunner countries is characterized by, inter alia, increased investment in research and development (R&D), development of competitive R&D infrastructure, interdisciplinary education and training system together with development of entrepreneurship, technology transfer and innovation and, contribution to economic growth.
- Reconfiguration of existing institutional structures and evolution of new forms of collaborative arrangements between various actors and policies has emerged as an important factor enabling these countries to remain forerunner in nanotechnology.
- The R&D focus in nanotechnology globally is diverse with countries developing technologies in areas corresponding to their own expertise and needs. There is a need for development of clear national strategies to utilize nanotechnology to meet social priorities.
- A deliberate innovation policy in nanotechnology with the government acting as a guide in areas where market signals are weak and are not sufficient on their own is important for alignment of nanotechnology with overall societal goals.
- To engage with nanotechnology successfully, developing countries would need to address a range of issues pertaining to research, technology development, skills requirement, institutions involved, risks issues, regulatory and governance structure and stakeholder engagement.
- Nanotechnology development in India is at a nascent stage with policy initiatives directed towards promoting research and development. It is largely a government led initiative and industry participation is still emerging. A more inclusive science and technology (S and T) policymaking process and integrated framework is needed to ensure that this technology is diffused and used for socially valued goods.
- The likelihood of adverse impacts to environment and human health as well as consumer and worker safety exists along the life cycle of nanoapplications. Given the variety of nanomaterials and their broad spectrum applications, the nature of hazards from these substances might be varied and even unforeseen. However risks from nanotechnology based materials and products would depend on the nature of impacts and the degree, stage and duration of exposures.
- An inclusive and responsive risk governance structure to address multi-dimensional risks from nanotechnology is imperative. There is a need to put in place adequate structures to carry out risk assessment procedures and ensure laws and policies that would address the liability and redress issues inherent in the application of nanotechnology having unknown environmental and health impacts.
- Regulatory oversight for nanotechnology is necessary to channelise research efforts in a responsible direction. The regulatory regime for nanotechnology needs to be dynamic and should be reviewed from time to time. Transparency and public involvement in the design and implementation of regulatory structure in nanotechnology should be ensured.

Nanotechnology developments: an overview

Nanotechnology, which deals with understanding and control of matter at dimension of roughly 100 nm and below, has a cross-sectoral application and an interdisciplinary orientation. At this scale, the physical, chemical and biological properties of materials differ from the properties of individual atoms and molecules or bulk matter, which enable novel applications. Nanotechnology research and development is directed towards understanding and creating improved materials, devices and systems that exploit these properties as they are discovered and characterized.[1]

There are many applications of nanotechnology such as in the area of medicine, chemistry and environment, energy, agriculture, information and communication, heavy industry and consumer goods. The alleged potential of this technology has garnered the attention of both developed and developing countries across the globe. The US National Science Foundation (NSF) has listed it as one of six priority areas; it is one of the themes in the EU Framework Program for Research and Technological Development in Europe; and it has been the focus of research in countries worldwide. Globally, investments have been made, nanotechnology programmes initiated and research and development has commenced. It is observed that US, Japan, and Germany dominate the current R&D effort in nanotechnology with the country focus largely based on their own expertise and needs. Globally, there has been an increase in expenditure by both governments and private companies in nanotechnology developments. Total global expenditure (public + private) in nanotechnology R&D in 2007 amounted to $13.5 billion, up 14% from in 2006. Expenditure by corporations in nanotechnology R&D in 2007 witnessed a 23% increase over 2006 to reach $6.6 billion, passing government spending for the first time.

At the commercial level, the impact of nanotechnology, is evident in three major industry sectors, viz., materials and manufacturing (coatings and composites for products like automobiles and buildings), electronics (displays and batteries) and health care and life sciences (pharmaceutical applications). According to the Woodrow Wilson International Center for Scholars' Project on Emerging Nanotechnologies (2009),[2] there are more than 1000 company-identified nanotechnology products on the market, the majority being produced by companies based in USA. The categorisation of nanotechnology products indicates a concentration in the fields of health and fitness products (cosmetics, clothing, personal care and sporting equipment) (Figure 1.1). The analysis of the product category suggests that nanotechnology mainly impacts the consumer goods industries. An estimate by Lux Research indicates that nanotechnology-derived revenues will attain 15% of projected global manufacturing output ($2.6 trillion) in 2014 as compared to 0.1% in 2006 ($50 billion).

[1]The National Nanotechnology Initiative Strategic Plan, Nanoscale Science, Engineering, and Technology Subcommittee, National Science and Technology Council, The White House December 2007.

[2]See www.nanotechproject.org

Country	Number of products
USA	563
Germany	78
Japan	43
Korea	139
China	56

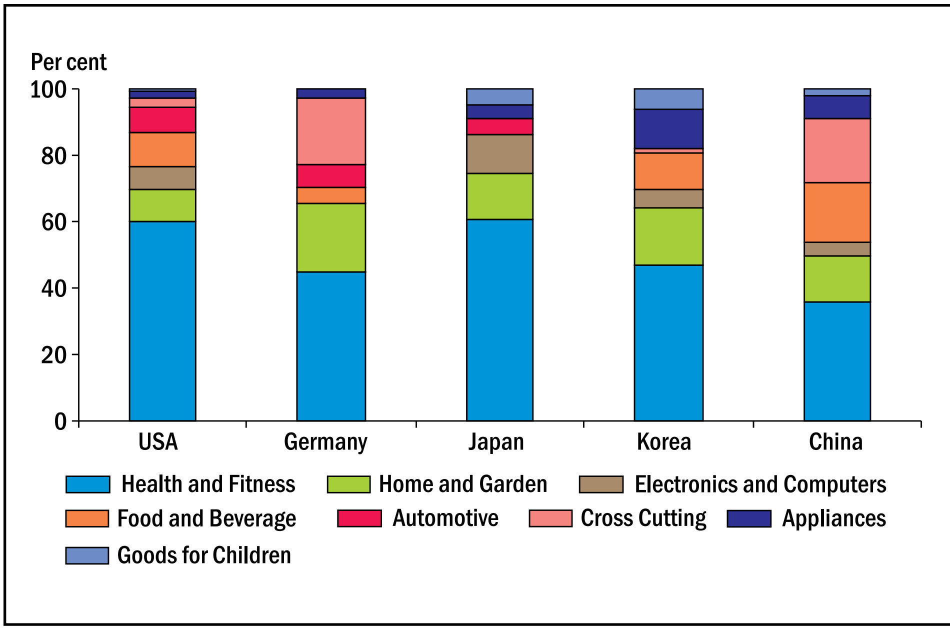

Figure 1.1 Percentage shares of different categories of nanotechnology products by country, October 2009

Source Woodrow Wilson International Centre for Scholars (www.nanotechproject.org)

Nanotechnology initiatives in India

The emergence of nanotechnology in India has witnessed the engagement of a diverse set of players, each with their own agenda and role. Nanotechnology in India is a government led initiative. Industry participation has very recently originated. Nanotechnology R&D barring a few exceptions is largely being ensued at public funded universities as well as research institutes. An overview of the key players engaged in nanotechnology in India is given in the Figure 1.2.

Given the enabling nature of nanotechnology and ability to develop along with existing technologies, it has the potential to be utilised as a tool to address key development related challenges in diverse sectors like energy, water, agriculture, health, environment and the like. Enabling energy storage, production and conversion within renewable energy frameworks has been cited as the primary area where nanotechnology applications might aid developing countries. Nanotechnology interventions might be sought at specific junctures to improve quantity and quality of water and wastewater treatment systems. Enhancement of agricultural productivity has been identified as a critical area of nanotechnology application nanotechnology for attaining the Millennium Development Goals. In light of the developments worldwide hailing nanotechnology as a technology with the potential of addressing a number of developing country needs, India has sought to promote nanotechnology applications in sectors that are likely to have a wide impact, and influence the course of future development in the country. Sectors such as health, energy and environment have received greater attention by various technology departments in the government (DST, DBT and SERC). Figure 1.3 shows the distribution of sponsored projects from 2006 to 2008 across key sectors.

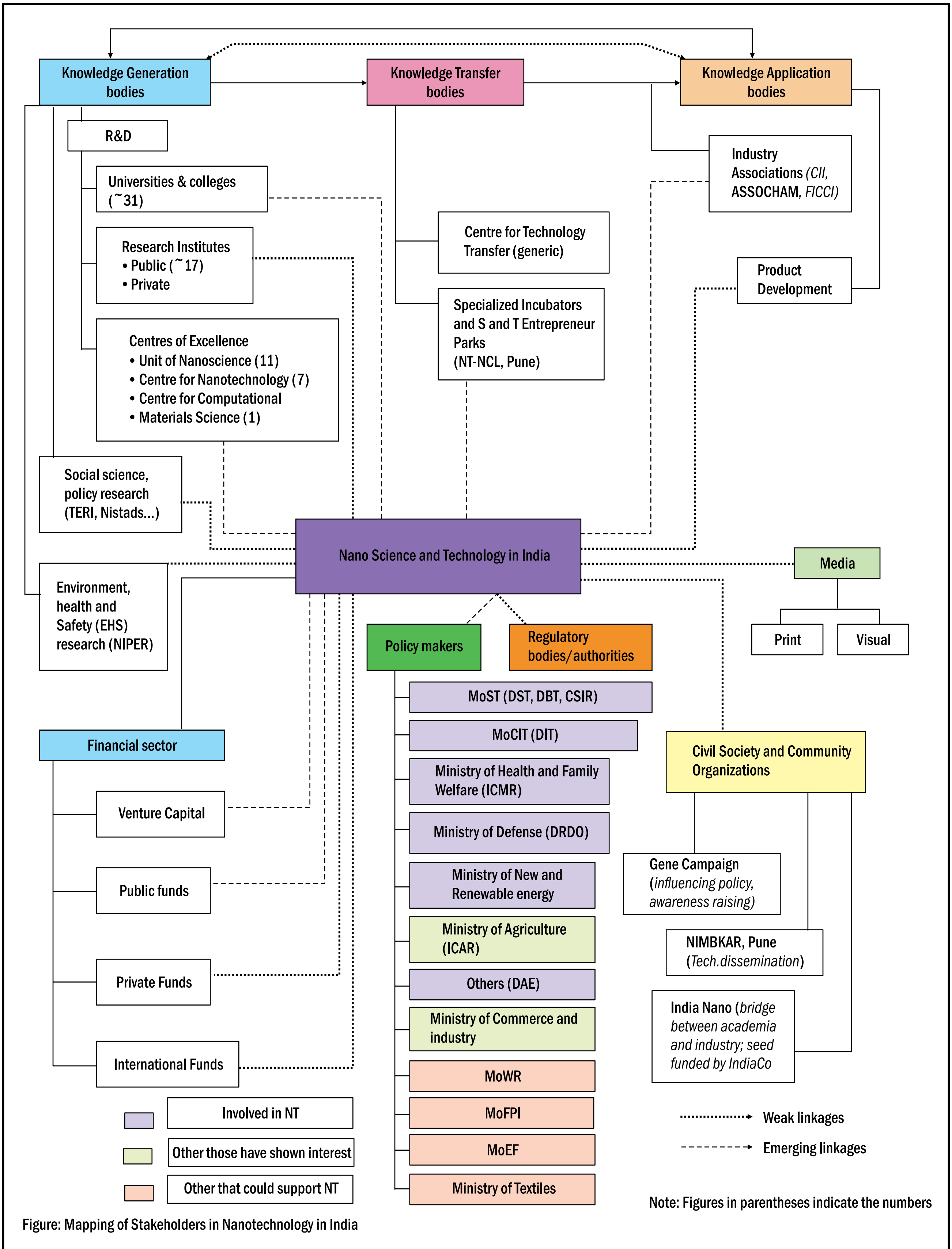

Figure 1.2 Map of stakeholders in Nanotechnology in India

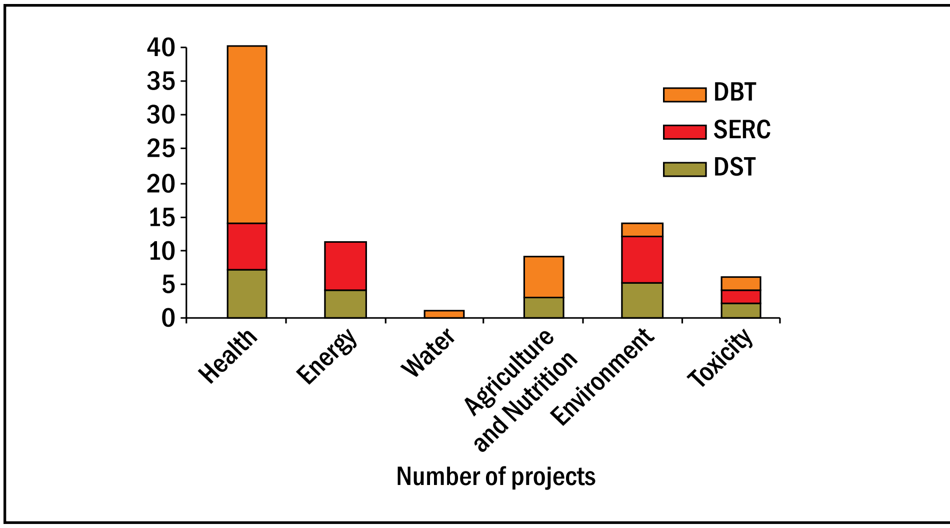

Figure 1.3 Sectorwise distribution of projects sponsored by DST, DBT and SERC – 2006–08
Source http://nanomission.gov.in/

Department of Science and Technology (DST), the chief agency engaged in the development of nanotechnology, initiated India's principal programme, the Nanoscience and Technology Mission (NSTM) in 2007, with an allocation of Rupees 1000 crores for a period of five years. The five-year programme followed the flagship initiative, the Nanoscience and Technology Initiative (NSTI) that was in operation from 2001–06. Close to 200 projects have been undertaken in the NSTI and NSTM since 2002 (Figure 1.4). The DST has also set up 'Centers of Excellence (CoE) for Nanoscience and Technology' established under the NSTI to undertake R&D to develop specific applications in a fixed period of time. On the whole the 19 CoE have been spread across 14 distinct institutions (Figure 1.5). These CoE have been set up primarily at those institutes that have either been engaging in nanotechnology based R&D prior to their establishment or have developed the resources to do so. Aside DST, several other agencies with diverse mandates are also actively engaged in supporting

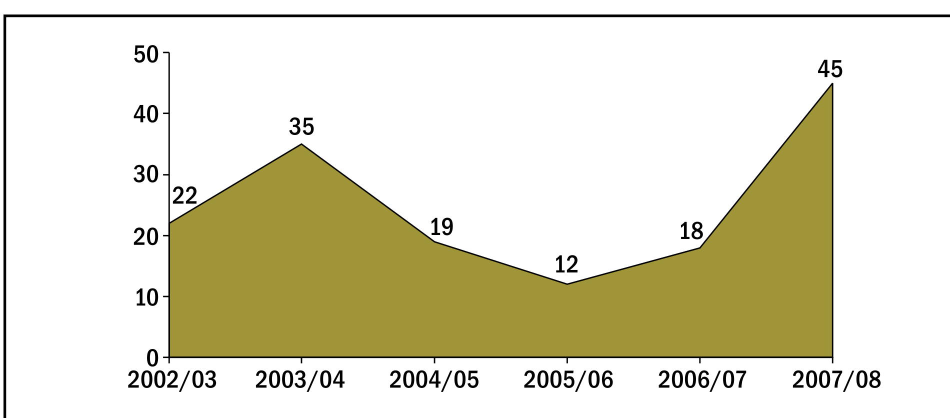

Figure 1.4 Number of project sanctioned under NSTI and NSTM
Source http://nanomission.gov.in/

nanotechnology in the national arena. DBT (Department of Biotechnology) is supporting research in nanotechnology and the lifesciences. CSIR (Council of Scientific and Industrial Research), a network of 38 laboratories that engages in scientific and industrial R&D for socio-economic benefit has also commissioned R&D in nanotechnology in diverse areas. SERC (Science and Engineering Research Council) too has aided projects on nanotechnology. Support for these projects has been through its general R&D schemes for basic science and engineering science.

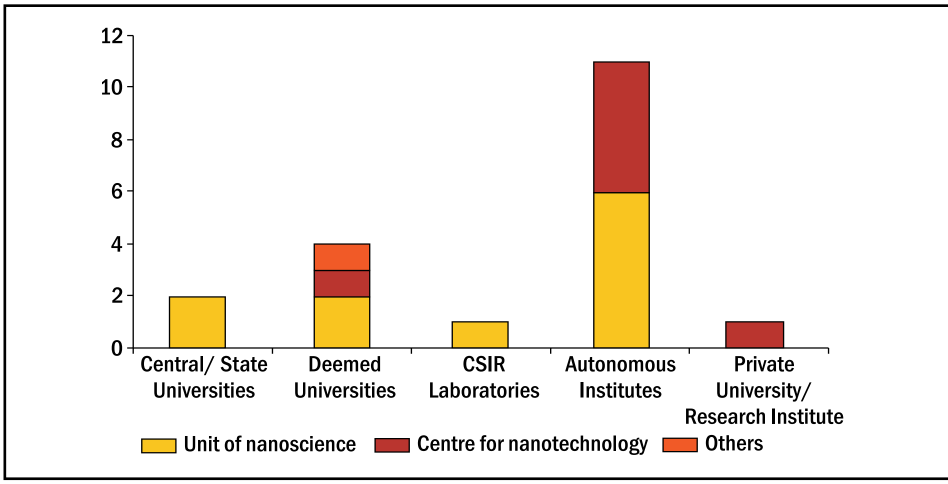

Figure 1.5 Distribution of Centres of Excellence across the various categories of R&D institutes
Source http://nanomission.gov.in

India's International Collaborations

Several bilateral collaborations emerged in nanoscience and technology, as it was a part of nearly all the S&T agreements between India and other countries. Initiatives for joint R&D have figured prominently with Indian institutes engaging in projects of similar kind in the US, EU, Japan, Taiwan and Russia. The S&T departments of Brazil, South Africa and India have embarked on a tri-lateral initiative to developed collaborative programmes in several common areas of interest, and nanotechnology being one of them. Other initiatives include Science and Technology Initiatives with Indian diaspora – Scientists and Technologists of Indian Origin Abroad (STIOs) for encouraging networking between Indian scientists and scientists and technologists of Indian origin that are based abroad. The International Science and Technology Directorate (ISAD) of the CSIR that aims to strengthen cooperation between CSIR and international institutions has facilitated workshops and collaborative projects with international partners like South Africa, France, South Korea, China, Japan in the area of nanoscience and technology. Another forum for international collaboration is the Euro-India Net set up under the FP6 between EU and India to encourage collaborations between scientists from the two regions in the area of nanotechnology. A memorandum of understanding also has been signed between India and UNESCO to establish a Regional Centre for Education and Training in Biotechnology, where one of the focus areas is on nano-biotechnology.

There is a clear emphasis on fostering public–private partnerships (PPP) to meet the demands of developing a capital-intensive technology such as nanotechnology. The Nano Mission lays down as one of its objectives that 'special effort will be made to involve the industrial sector into nanotechnology R&D directly or through PPP ventures'. Of the six PPP launched under the Mission, three are in the pharmaceutical sector. CSIR's flagship program New Millennium Indian Technology Leadership Initiative (NMITLI), India's largest public–private partnership scheme also has a few nanoprojects under its umbrella and is an initiative by the government to get industry on board with public funded R&D. A Planning Commission study has called for the creation of a National Institute of Nanotechnology in Agriculture (NINA) under National Agricultural Research System.

Formulating national strategies and building capabilities to engage with nanotechnology

Developing clear national strategies to engage with this emerging technology is imperative. It is imperative to link technology developments with social priorities and goals. The role of the state would be imperative in charting the trajectory of nanotechnology developments in developing countries. In general, in developing countries, the share of public investment in total nanotechnology R&D basket is relatively greater in comparison to private sector. Although the growing importance of private sector cannot be underestimated, but given that technology base for nanotechnology being in an embryonic phase, industry would not be able to sustain the research effort needed for the establishment of scientific and technological infrastructure. Therefore, there is a stronger case for the role of government support for fundamental research. The government has played a predominant role in research effort in nanotechnology in terms of funding, establishing the scientific and technological infrastructure and developing human skills and capacity. The dynamics of the sectors in terms of the nature and composition of research infrastructure and the level of technology production would determine to a great extent the role of agencies in support for research. For instance research support for application of nanotechnology in IT sector could be private agency driven. However, in the energy, health and other development sectors, the government should play an active role in providing research support for nanotechnology applications.

The role of the state is also of prime importance in defining regulatory objectives, developing the ambit and then selecting the tools from the toolkit that would best facilitate the achievement of the objectives. Normally, the government priority at a given point of time also influences regulatory choices made. However, the State should strike a balance between promoting a technology and regulating its risks. Furthermore, the State can play a crucial role in resisting pressures of globalisation in the context of technology development. International trends in R&D lead to the development of certain products that can be classified as either high-end luxury goods or quality enhancement of products that benefit a small segment of society. The state particularly in the developing country context can set the agenda and resist the tendency to uncritically follow international trends in research that do not address their developmental needs.

Conceptualising national capability

A conceptual framework to assess national capability to respond to nanotechnology development needs to address the key opportunities and challenges created by this technology for developing countries in terms of the demands imposed on the science and technology infrastructure and by changing the nature of science and technology. Several issues emerge from the review of international developments in nanotechnology:

- there is a need for strong infrastructure to enable and stimulate R&D and commercialisation of nano products;
- constraints and concerns among users must be addressed for successful deployment of technology;
- appropriate strategies, policies and institutions are needed to engage with an emergent technology;
- human resources with multidisciplinary perspectives is key for progress in nanotechnology;
- there is a need for addressing nanotechnology risks in the societal context;
- regulatory oversight and preparedness for nanotechnology is necessary to channelise research efforts in a specific direction;
- capacity building of regulatory and monitoring agencies
- transparency and public involvement in the design and implementation of regulatory structure in nanotechnology should be ensured.

Developing capabilities in emerging technologies thus would require: (a) skills of both scientific and non-scientific kind, including regulatory bodies, (b) a greater degree of linkages between various actors from academia, industry, policy makers would be necessary for successful market deployment of such technologies, (c) the interdisciplinary approaches in nanotechnology would demand a different R&D strategy as well as reorientation of science and technology activities in universities, research

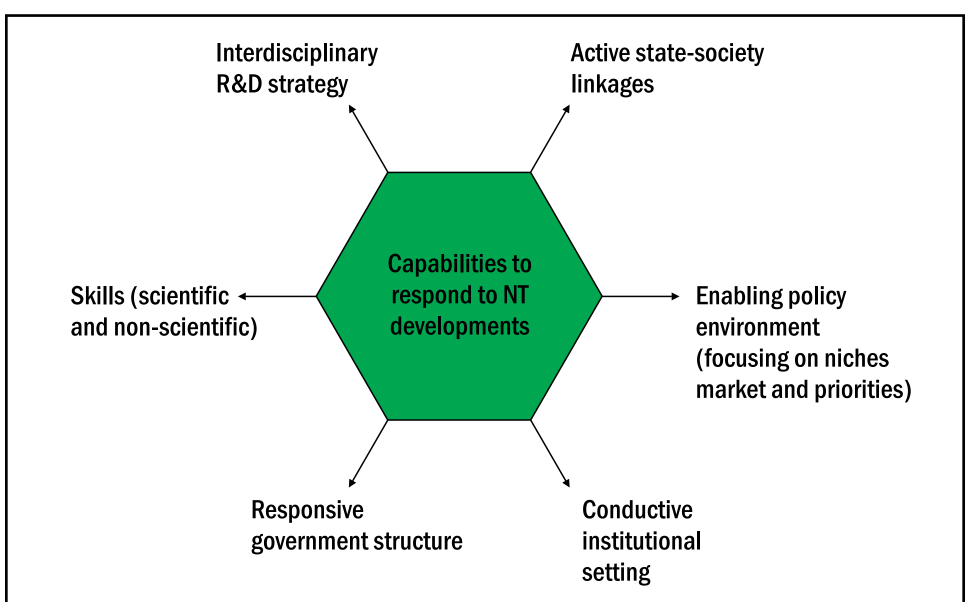

Figure 1.6 Capabilities to respond to nanotechnology developments

institutes, funding agencies and industry with a conducive institutional setting facilitating interactive learning would be essential to respond to and develop nanotechnology, (d) devising adaptive and responsive governance structures that can suitably regulate applications of nanotechnology in society, and (e) a flexible, dynamic policy environment that has the ability to create the conditions required for both knowledge generation and its effective utilization would form an important dimension guiding the process of development of capabilities. See Figure 1.6

Attendant benefits and risks

Benefits

Nanotechnology today is regarded as a revolutionary technology. Worldwide, there has been an increasing interest in nanotechnology as evident from the rising trends in investment and policy initiatives directed towards this end. Nanotechnology can enable cost effective solar and fuel cells with higher efficiency. Nanomaterials could also facilitate energy saving through nanomaterials aided efficient lighting (LEDs), nanocatalysts that improve combustion processes and also better insulation materials. Overall nanotechnology interventions could enable the successful development of renewable energy solutions and reduce our dependence on fossil fuels. Enhancement of agricultural productivity has been identified as the second most critical area of application of nanotechnology for attaining the Millennium Development Goals. Nanotechnology is believed to enhance agricultural productivity through genetic improvement and make crops more resistant to heat and water logging. Water treatment and remediation has been cited as the third most critical area where nanotechnology applications might aid developing countries. Some of the interventions include water purification, detection of contaminants and waste water treatment.

Risks

Nanotechnology risks can be best understood in conjunction with its benefits. The complexity of the technology, the breadth of nanomaterials and applications, coupled with the possibility of its wide dissemination in the globalised world renders the technology unpredictable in many senses. The risks are heterogeneous as the field of nanotechnology itself and include environmental, health, occupational and socio economic risks.

The unusual properties of nanomaterials that can enable rewarding applications for society might pose unknown or unforeseen environment, health and safety challenges. The pro-technology stance taken in several developed and developing countries at the cost of risk related research has led to an information gap around the impacts of nanomaterials. These aspects together with the commercialization and pervasiveness of nanoproducts serve to heighten the risk from this emergent technology.

By virtue of their size, nanomaterials like other tiny particles might be able to enter the human body and those of other species imperceptibly through various pathways- inhalation, ingestion, dermal contact, etc. Early research also indicates that nanoparticles could reach various parts of the body where they may exert adverse effects. Nanoparticles, it is believed might be able to disrupt cellular, enzymatic and other organ related functions posing health hazards. On the other hand nanoparticles might also be non-biodegradable and on disposal, these disposed materials might form a new class of non-biodegradable pollutant and pose a new threat to the environment (air, water, soil) and health. In light of these facts it appears that the greatest current risk is to the occupational health of the workers involved in the production, packaging or transport of the nanomaterials. With the increase in the application of nanomaterials in various products, the risk of the exposure of the consumers and the general public will also increase. Therefore it is crucial to examine and estimate the risk for regulating the production, use, consumption and disposal of these materials.

In this context the use of life cycle analysis (LCA) has been encouraged as a first step to understand the risks from nanoapplications during their entire life cycle-from cradle to grave. Despite lack of substantial data on EHS impacts, LCA can be vital in identifying and evaluating potential risks from nanoapplications and also serve to identify crucial knowledge gaps.

Currently, there is clearly a lack of emphasis on risk related research in nanotechnology. Even where risk aspects are looked at, several gaps and challenges exist in the sphere of undertaking studies related to toxicity and EHS impacts. These include lack of information on the nature and characteristics nanomaterials in applications, insufficient methods for detecting and measuring nanomaterials, inadequate breadth of risk related research. These issues must be addressed alongside conducting appropriate kinds of tests and interdisciplinary research to accurately elucidate the risks of nanomaterials and products. Providing adequate investment to fund robust risk research, including regulatory toxicology, is necessary to both address and anticipate risks accruing from nanotechnology.

Given that nanoproducts are already in the market, LCA studies and risk assessments must be emphasized in order to address the nature and extent of risks from these applications. Further, there is a need to understand the trade-offs that may have to be made between the risks of nanotechnology applications and the risk that emerges from lack of access to the technology.

It is likely that nanotechnology would have major impacts on the existing social, economic and trade milieu as well as on global markets and commodity driven industries. History shows that past introductions of major technological interventions in the global community have resulted in socio-economic impacts in vulnerable communities. However, the nature and extent of such risks would depend on the nature and extent of commodity dependence of the respective countries. It would also depend upon whether nanotechnology application substitutes the use of the commodities or whether it complements the existing use of the commodities. Policies have to be implemented to reduce the vulnerability of commodity dependent developing countries in the context of emergence of socio- economic risks from nanotechnology applications.

Development of an adequate risk governance framework for addressing risks that surround nanotechnology is vital for the responsible development of nanotechnology that allows reaping benefits while minimizing risks.

Life Cycle Analysis of a nanosilver based candle filter

Given the rapid commercialization of nanosilver based products worldwide, an LCA was attempted for a nanosilver based candle filter. Confining itself to the nanosilver related processes, the goal of the LCA was to examine the nature of nanosilver related emissions, routes of environmental and human exposures as well as understand the likely EHS impacts of the associated releases. The analysis revealed that during the life cycle of the product, water borne emissions are most likely although airborne emissions might also occur. However it pointed out the uncertainties regarding the nature of the emissions as they may in the form of silver nanoparticles, silver or silver ions. Calculations drawn from the limited data inventory revealed that during consumer use, releases might be anticipated in the drinking water. In the absence of precautionary measures, health related exposures are likely through dermal contact and inhalation although ingestion of silver or silver nanoparticles is possible during consumer use. Releases into surface water bodies and soil might result from effluent discharge or disposal in landfills. The study emphasized that the magnitude of emissions and duration of exposure are likely to be high at production sites, therefore it is essential that workers are equipped with adequate protective gear. It also underscored that much could be drawn from the known EHS impacts of silver especially in the face of the premature nature of the data on the risks from silver nanoparticles. For example the large scale exposure to silver that has been implicated in the discoloration of skin and other body parts (termed as argyria) might also be expected on exposure to silver nanoparticles. The analysis from our study revealed that certain concentration of silver per day might be consumed by users of the water filter. Although this concentration is less than the WHO limits for causing argyria, our study emphasizes that long term use of the candle or greater releases of silver might pose a risk to consumers. On the other hand it is also clear that silver nanoparticles due to their unusual properties might pose other adverse impacts like transport to various other organs, toxicity to liver cells, damage to DNA, etc. Other studies have pointed out that both silver and nanosilver particles are known to be toxic to certain aquatic species. Appropriate treatment facilities for waste generated by the manufacturing units will serve to reduce environmental risk.

Overall it emerged from the study that the large scale manufacture and use of nanosilver applications could induce adverse health and environmental impacts. However the case study demonstrates that although nanomaterials could be potentially hazardous, risks from nano applications will depend on not only the nature of the potential hazard but also on the magnitude and the frequency of exposures, the bioavailability of the either silver or silver nanoparticles and the ability of the humans and other species to detoxify these substances. The study also points out that strategies to mitigate releases (effluent treatment and municipal treatment plants, recycling candles) along with adequate regulatory oversight may reduce risk of environmental impact from silver discharges, it is unclear if releases of silver nanoparticles can be contained by these conventional methods.

Formulating a risk governance framework

One of the chief reasons behind the categorisation of nanotechnology as an interdisciplinary technology can be found in technological systems convergence. Given its organic and inorganic applications, nanotechnology is very amenable to convergence processes. Technology convergence also draws together state and non-state actors (here, pharma MNCs and specialised international associations) who are increasingly engaged in governing and regulating transnational issues, which include technology transfer. In this regard, it is necessary to locate these actors within the broad rubric of institutional capacity, which would constrain and enable the development of an emerging technology to a significant extent. Institutional capacity, which includes the assets, skills and capabilities, constitutes the knowledge structure within a given society. The extent to which this knowledge base can grow depends on certain other factors that are extraneous to the immediate interests of the scientific community itself. For instance, denial of access to technology due to a restrictive patent regime can limit a country's capacity to benefit from it. Furthermore, every risk governance framework should seek to include stakeholders who are affected by the regulation, production and consumption of nanoapplications. Risk governance would include the laws, processes and institutions by which decisions regarding risk analysis, communication and management are taken and executed. It takes into cognizance both the structures (i.e. the actors who are the participants involved in the decision making process) and the process (i.e. the procedures that make decision making legitimate and participatory within the overall governance framework). An inclusive risk governance framework then would entail democratizing science by strengthening the involvement of key actors – policy makers, regulators, business, scientific and civil society communities. This inclusive framework would ensure that the debate around risks emanating from nanotechnology is not polarized. This entails an unbiased and transparent risk communication and upstream engagement with all stakeholders to address the hype or fears that surrounds the technology.

While local and national capabilities to undertake research as well as decisions on risks is built, developing countries must engage with the global community to develop standardized protocols, reference materials and other databases. A long term and dynamic strategy to address the issue of EHS impacts and risk from nanomaterials and nanoapplications is essential.

Evolving a dynamic regulatory framework

One of the key debates around nanotechnology regulation has been around whether there exists a need for a separate nanotechnology specific law to regulate the concerns around nanotechnology or not. A close look at the existing set of laws and rules in different areas of current and potential nanotechnology applications suggests that a nanotechnology specific legislation may not be necessary at this stage in India. Most of the challenges and concerns could be addressed by way of either intervention at the level of subordinate legislation or amendments in the existing instruments, or interventions at the level of implementation. Moreover, since nanotechnology being an emerging technology is still surrounded with uncertainty and lack of enough information about its impacts, instead of a definite nano-specific law, ensuring the capacity of existing regulations to address new risks as they become known would be the viable course forward. Applications of nanotechnology, owing to their very nature, interaction with other technologies, and extent are subject to several regulations already. However, most of these existing regulations require revision before they are able to regulate the risks associated with nanotechnology. In this context, precautionary principle, which has already been adopted in environmental regulation, should be extended to nanotechnology regulation, considering the uncertainties. However, the principle should be applied in a judicious manner taking a middle ground, reconciling the need to address risks and using the technology to address development needs.

Internationalisation of regulation

There has been a growing trend towards the acceptability of international forums/institutions as efficient and effective sites of regime creation. These sites are characteristically sub-political in nature in as much as they lack effective legitimacy and formal rule making power. The Intergovernmental Forum on Climate Safety (IFCS), International Standards Organization (ISO), and the International Risk Governance Council (IRGC) are three such sites that can be identified. Sub-political sites as compared to the arena of formal politics inherently suffer from a democratic deficit so crucial to provide legitimacy to their decisions. These sites therefore prefer indirect means of policy implementation. Thus another aspect of the impact of these institutions on the formal policymaking process is the indirect channel of influence that they exercise. Given that the Indian domestic regime for nanotechnology regulation is still at a nascent stage and essentially reactive in nature, the deliberations within these two sites could have considerable influence in its development and functioning.

Challenges and approach

Challenges to technology development

- Producing the nanomaterials in large enough volumes, with consistent quality, at acceptable costs.
- Supplying the nanomaterials in a form (such as proper particle size, surface chemistry, dispersion capability, compatibility with various media, etc.) that would allow integration into the process.
- Engineering and customizing the nano-based system to local requirements.
- Addressing environmental, health and safety concerns in the use and disposal of nano products.

Challenges to technology governance

- One of the biggest challenges has been in terms of the interdisciplinary nature of nanotechnology per se and the scope of its applications. This has lead to significant overlaps in the areas for R&D support identified by different agencies.
- The gap between basic research and application is another challenge in nanotechnology, like several other technologies. There is poor lab-firm integration which is compounded by the paucity of skilled manpower that could provide linkages between the technology and commercial domains.
- Being cost and risk intensive, and being dependent upon sophisticated and complex equipment, technical know-how and capacity, financial constraints often act as an impediment in this regard.
- The main challenges faced by regulatory institutions currently relate to the regulatory capacity, information asymmetry and absence of inter-agency coordination.

- Another challenge that nanotechnologists should address in their research is due priority to risk research. Currently, funding allocated for analysing risks from nanotechnology is abysmally low compared to the vast amounts invested for its commercial applications. On the other hand, other experts argue that research related to toxicity and risk assessment must be undertaken once the applicability of specific nano-applications are ascertained, especially when the prototype of the product has been developed and is available for field testing. This strategy might help enable a balanced approach between technology development and addressing risk issues. Moreover, it could also facilitate the judicious allotment of already constrained financial resources as well as prevent an overzealous focus on risk issues especially in the nascent stages of product development that might in turn prevent the emergence of socially useful and significant applications.
- Venture capital mechanisms are nearly non-existent. This made taking research forward to technology development in this arena sluggish.

Towards responsible nanotechnology development

Given that nanotechnology is comprehensive in its reach and interdisciplinary in nature, ensuring the accountability of actors involved in its application and regulation is essential. Its socially embedded nature entails that its credibility depends on fostering partnerships among the various stakeholders.

This would ensure that scientific research does not overwhelm public perception and the social analysis of technology, an approach that would be particularly relevant in the case of nanotechnology governance. Currently, there exists a trust deficit between the optimism of the scientific community and the apprehensions expressed by public interest groups regarding nanotechnology's potential. Bridging this gap would be critical in determining the extent to which India can avail of international opportunities to enhance its capabilities on the development front.

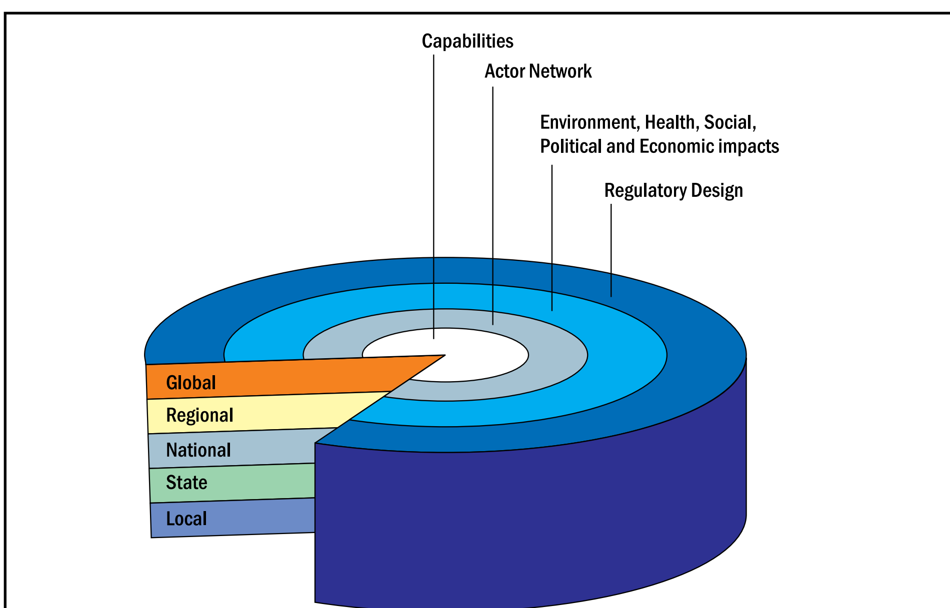

Figure 1.7 Multilevel governance framework for nanotechnology

A comprehensive governance framework has to transcend all the vertical and horizontal levels involved in the development and application of technology. Horizontal level refers to distributed responsibilities between national government departments, statutory bodies, and other non-government groups in engaging with nanotechnology developments, capabilities, networking, environmental, health socio-economic and political impacts, and designing a regulatory framework. At a vertical level, the framework spans global, regional, national, state and local nanotechnology developments and policymaking. Adopting such an approach would enable integration of relevant perspectives on issues, challenges, prospective emerging applications and factors that will be influential in determining the development pathways for nanotechnology.

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