# Nanoscience and nanotechnology: ethical, legal, social and environmental issues

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*The present article attempts to understand the debate over nanoscience and nanotechnology regarding its potential benefits to the society. One view in this debate is that nanoscience and nanotechnology has a revolutionary potential and will have significant economic benefits, while the other view is skeptical about its potential in the context of ethical, legal, social and environmental (ELSE) issues and values such as equity and justice. In some developed countries, discussion on the ELSE issues of nanoscience and nanotechnology has already begun. Hence, there is a need to take a cue from the debate in the developed countries and focus our attention on these issues in the Indian context. The ELSE issues should be addressed right from the beginning of the development of nanoscience and nanotechnology, so that it is possible to make informed policy decisions.*

**Keywords:** Benefits and issues, nanoscience and nanotechnology, regulatory mechanism, risk.

IT is now well accepted in the science, technology and society (STS) studies literature that technology can be said to have its own specific knowledge claims and also that technology is socially shaped[1]. In a rough and ready sense, social groups are said to play a major role in shaping the development of a new technology (and nanoscience and nanotechnology is no exception). There are various competing approaches and accounts of how to explain this social shaping. For example, the social construction of technology (SCOT) approach developed by Bijker *et al.*[2] takes the idea of users as agents of technological change as well as design and technical content of technological artifacts as important explanatory factors in social shaping. In the SCOT approach the social groups exercise influence in shaping technology through institutional means. A complementary approach, stemming largely from the work of Hughes (in Bijker *et al.*[2]), treats technology in terms of a system metaphor. This approach stresses the importance of paying attention to different but interlocking elements of physical artifacts, institutions and their environment, and thereby offers an integration of technical, social, economic and political aspects. Shaping the development of a new technology in the later part of the 20th century has been informed by the large-scale impact that technology has had or may have on various domains, including ethical, legal, social and environmental (ELSE) issues. The probability or possibility of any specific impact that technology may have on issues related to ELSE has often been understood through the mediations of an analysis of risk. The controversies that the world has witnessed and continues to do so concerning various kinds and degrees of risks associated with many technologies, highlight the possibility of analysing the question of development of a technology (including nanoscience and nanotechnology) in terms of how different stakeholders understand, highlight or attenuate the risks associated with a technology and also bring to bear their understanding in promoting or questioning the development of a technology.

Controversies over technology also represent in part a loss of public trust, a declining faith in the ability of representative institutions to serve the public interest[3]. The debate over nanoscience and nanotechnology may be seen as a part of scientific controversies as well as public disputes. Nelkin[3] provides a typology of controversies in science. According to her, first, the most intense and intractable disputes concern the social, moral or religious implications of a scientific theory or research practice. A second type of controversy relates tensions between environmental values and political or economic priorities. A third type of controversy is regarding the health hazards associated with industrial and commercial practices, and the resulting clashes between economic interests of those involved in such practices and the people concerned about risk. A fourth type of controversy over technological applications reflects the tension between individual expectations and social or community goals. Characteristically, such controversies, reflecting the disputes over government regulations on account of introduction of science and technology, are framed in terms of ‘rights’. The debate over nanoscience and nanotechnology spans across the first three types of controversies pointed out by Nelkin.

The present article has two sections. In the first section, we present a brief account of the initiatives that were

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taken to promote nanoscience and nanotechnology in different countries, potential applications and the controversies based on arguments put forward by the enthusiasts in favour of nanoscience and nanotechnology, and those of the skeptics who seem to base their arguments on scientific limitations. In the second section, we discuss a specific issue concerning the need for a regulatory mechanism in India, given the probable and possible risks associated with the development of nanoscience and nanotechnology by drawing upon the findings of a recently concluded research study on the nanoscience and nanotechnology community in India. The variability in the perceptions regarding risks and regulatory issues is explained in terms of how scientists legitimate their work with reference to (assumed) permission granted by the norm authority – be it the government, the scientific community, or the wider society.

## Initiatives, potential applications and controversies

Nanoscience and nanotechnology is about the precise and purposeful manipulation of matter at the atomic level. Burgi and Pradeep[4] provide a comprehensive account of the development of nanotechnology. The modern conceptual underpinning of nanoscience and nanotechnology was laid by the physicist Richard Feynman (1959) in his lecture 'There is plenty of room at the bottom'[5]. The scanning tunnelling microscope (STM), a novel measuring instrument invented by Gerhard Binnig and Heinrich Rohrer, who were awarded the Nobel Prize for their invention in 1986, enabled scientists to 'see' matter at the nanoscale and 'manipulate' matter at that level. This is an example of a technology that played an important role in opening up a new field of scientific inquiry. Increasing thrust of the electronics industry, which aimed at developing tools to create smaller devices on silicon chips, was one of the primary driving forces during the 1980s for the emergence of nanoscience and nanotechnology. In other words, utilitarian considerations underpin the research agenda.

The utopian nano-futures and the implied industrial, social and political scenario portrayed by Drexler[6] and others attracted a great deal of attention in the early 1990s. But scientists were clearly expending a great deal of effort to establish distinct boundaries between what they saw as legitimate research and nano-visions that seemed to have more in common with science fiction than laboratory realities[7].

During the mid-1990s, Roco and his group promoted nanoscience and nanotechnology research as a national priority in the US[8]. The National Science Foundation (NSF), USA, established the National Nanotechnology Initiative (NNI) in 2000, to support research in the area of nanotechnology. Developing countries, which hitherto found themselves on the sidelines watching the excitement of technological innovation developed in the advanced Western countries[9] are now poised to rewrite the script in nanoscience and nanotechnology. Countries like China, South Korea, India, Thailand, Philippines, South Africa, Brazil, Chile and Mexico have already started investing resources in the area of nanoscience and nanotechnology. These countries have set up laboratories in numerous research institutions, developed national government funding programmes and introduced a few products of nanoscience and nanotechnology in the market.

In India, the government through the Department of Science and Technology (DST), New Delhi had established the Nano Science and Technology Initiative in the later part of 2001, and invested about Rs 350 crores (2002–06). Indian nanoscience and nanotechnology efforts cover a wide spectrum of areas, including micro-electro-mechanical systems (MEMS), DNA chips, quantum computing electronics, carbon nanotubes and biomedical applications. In May 2007, the Cabinet of the Government of India granted approval for the Nanomission and approved Rs 1000 crores for five years, starting from 2007. Legitimacy and funding for nanoscience and nanotechnology research are enhanced by endorsement and support extended by persons in public offices. A. P. J. Abdul Kalam, who was the President of India during 2002–07, a distinguished technologist himself, has been stressing the role of nanotechnology as a catalyst for economic development and stability. Kalam observes: 'Nanotechnology is knocking at our doors. It is the field of the future that will replace microelectronics and many fields with tremendous application potential in the areas of medicine, electronics, and material science.'[10]

### *Nanoscience and nanotechnology products*

Commercial applications of nanoscience and nanotechnology have begun to appear in various countries. For example, some US automotive companies like GM Motors and Chevrolet are already using clay nanoparticles, which make the materials stronger, lighter, more durable and often transparent. Smart textiles are also being developed. M/S Lee, a textile company that produces jeans, has already developed stain-resistant khakis. In the area of food, nanoscience and nanotechnology is being applied to study improved flavour delivery and maintainance of freshness.

In the areas of electronics and information technology, it is claimed that nanoscience and nanotechnology has the potential for smaller and faster computers with large memories. In the area of healthcare, it would be possible to create artificial organs and implant them in human bodies. Targeted drug delivery would be possible. In military, space and security, researchers are investigating smart materials that would be responsive to the conditions of their environment, sensors to detect chemical or biological warfare agents and lightweight bullet-proof materials.

Using molecular manufacturing, scientists have been exploring the potential for self-replicating nano-machines.

Several academic institutions in both public and private sectors in India have initiated nanoscience and nanotechnology research and development (R&D)[11]. The Council for Scientific and Industrial Research (CSIR), New Delhi, India's premier public R&D institution, holds numerous nanotechnology-related patents, including novel drug-delivery systems, production of nano-sized chemicals and high-temperature synthesis of nano-sized titanium carbide. Nano Biotech Ltd, an industrial enterprise in the private sector, has been doing research on nanoscience and nanotechnology for multiple diagnostic and therapeutic uses. Dabur Research Foundation is involved in developing nanoparticle delivery systems for anticancer drugs. Similarly, Panacea Biotech, a pharmaceutical company, has made advances in novel drug controlled-release systems. CranesSci MEMS Lab (a privately funded research laboratory located at the Department of Mechanical Engineering, Indian Institute of Science, Bangalore) is the first privately funded MEMS institution in India. It carries out product-driven research and creates intellectual property rights in MEMS and related fields[9]. Only a few companies like Raymonds and Eureka Forbes have launched a few products in India coming out of nanoscience and nanotechnology research. Some R&D institutions have been trying to establish interdisciplinary centres for nanoscience and nanotechnology research. Although in India impressive research initiatives have been taken, the research in the area of nanoscience and nanotechnology is still in its infancy compared to the degree of sophistication in R&D already achieved by the developed countries.

### *Rationale for investment in nanoscience and nanotechnology*

The rationale for investments committed by the R&D institutions is that nanoscience and nanotechnology is going to revolutionize the whole production process and products, and would bring changes for the betterment of the society. It was estimated by the European Commission in 2004, that funding for nanoscience and nanotechnology R&D is about 1 billion Euros, two-thirds of which comes from national and regional programmes. Similarly, in Japan, the funding rose from US$ 400 million in 2001 to US$ 800 million in 2003. US $3.7 billion has been allocated in USA to nanoscience and nanotechnology from 2005 to 2008, the funding being US$ 750 million in 2003. In the UK, with the launch of its strategy in 2003, the government pledged £45 million per year from 2003 to 2009. The national governments support research in nanoscience and nanotechnology for economic development on the basis of the advice provided by experts, who project the potential economic benefits of nanoscience and nanotechnology research.

### *The debate*

At this stage it is useful to present the arguments of the enthusiasts who project the revolutionary potential of nanoscience and nanotechnology and those of the skeptics who seem to question the revolutionary potential. Drexler[12], who founded the Foresight Institute to promote nanotechnology, states: 'self-replicating nanorobots could destroy viruses and cancer cells, and repair damaged structures, thereby eradicating disease and ageing'. Similarly, Joy[13] (Sun Microsystems), argues that the replicating and evolving processes that have been confined to the natural world can be brought into the realms of human endeavour. However, in contrast to the radically positive visions of the nanoscience and nanotechnology enthusiasts, some argue that the potential of this technology is exaggerated. Smalley[14] (one of the Nobel Prize winners in chemistry) questions the claims made by enthusiasts and points out physical limitations. He argues that nanorobots or assemblers 'are simply not possible in our world due to constraints imposed by the limitations of the scale'. Ball[15] (a science journalist) dismisses Drexler's ideas of nanorobots and submarines. He argues: 'the literal down-sizing of mechanical engineering fails to acknowledge that there may be better, more inventive ways of engineering at this scale'[15]. The basis of their argument is that the molecular manufacturing conception of nanoscience and nanotechnology does not fit within the laws of physics and chemistry as they operate at the nanoscale, or is redundant due to the superior power of biological processes.

### *Risk and its social amplification*

Risk is a potential harm to life, property or the environment. The development of science and technology remained largely unquestioned during the period of rapid economic growth that followed World War II. But by the 1970s, belief in progress was tempered by growing awareness of risks[3]. Since the 1980s, the term 'risk' has acquired a pervasive and even intrusive presence in almost all institutionalized discursive fields in the modern Western societies. Sociologists have presented theoretical accounts of the way in which risk has become a force of social change[16]. Douglas and Wildavsky[17] have focussed on the social functions of risk. Social amplification of risk is an important issue in the analysis of risk[18]. It refers to social consequences arising out of technical and economic risk. It may result in undesirable social consequences such as debt, poverty and destitution. In India, we are familiar with the social consequences of the Bhopal gas tragedy that occurred in 1984.

The general approach to assessing and controlling risk involves identification of hazard and then evolving a structured approach to determining the probability of exposure to the hazard and the associated consequences.

Risk is usually controlled in practice by reducing the probability of exposure. In any new technology, foresight of possible risks depends on a consideration of the life cycle of the material being produced. This involves understanding the processes and materials used in manufacture, the likely interactions between the product and the individuals or the environment during its manufacture and useful life, and the methods used in its eventual disposal. Risk analysis involves two elements: (a) judgement over acceptable level of risk and (b) time-frame over which a technology poses risk, which, as mentioned above, is related to the life cycle of the material. Judgement over the acceptable level of risk involves a complex interplay of competing and sometimes conflicting values[19]. For example, values of profit and safety may be in conflict in some situations. This conflict becomes a political battle over the values.

Scholars have been articulating perceptions of risk associated with nanoscience and nanotechnology on the basis of experiences with earlier technologies. Balbus *et al.*[20] point out that, as illustrated by the problems caused by asbestos, chlorofluorocarbons, DDT, leaded gasoline, PCBs and numerous other substances, the fact that a product is useful does not ensure that it is benign to health or the environment. They further warn that if the danger becomes known after the product is widely used, the consequences can go beyond human suffering and environmental harm to include lengthy regulatory battles, costly clean-up efforts and painful public-relations debacles. Fortunately, nanoscience and nanotechnology development and commercialization are still at an early stage, and so it is not too late to begin managing this process wisely[20].

Nanoparticles can be naturally occurring or arise as by-products generated by chemical reactions or engineered nanomaterials, which in fact are growing. Studies have demonstrated that some nanomaterials can be mobile or persist in the environment and can be toxic to animals. Through animals the toxicity can enter a biological food chain. Entry into the human body can occur through the skin, intestinal tract or lungs[21]. Some of these particles settle in the nasal passages (by inhaling), where they have been shown to be taken up by the olfactory nerves and carried past the blood–brain barrier directly into the brain cells[21]. Nanoparticles in the 30–50 nm range have been shown to penetrate deeply into the lungs and from there enter the systematic circulation[21].

Oberdorster[22] has shown that carbon-based particles known as fullerenes can have adverse physiological impacts on aquatic organisms like fish. The study also claims that the effects found in fish could be predictive of similar effects in humans. Nel *et al.*[23] claim that particles at the nano-level perform exceptional feats of conductivity, reactivity and optical sensitivity compared to bulk materials of the same composition. Possible undesirable results of these capabilities are harmful while interacting with biological systems and the environment, with the potential to generate toxicity. Oberdorster *et al.*[24] in their comprehensive review of nanotoxicology point out:

> . . . academia, industry, and regulatory government agencies should seriously consider the view that NPs [nanoparticles] have new and unique biologic properties and that the potential risks of NPs are not the same as those of the bulk material of the same chemistry.

They further argue that new toxicology data of nanosize form of a substance is likely to result in a different hazard assessment for the NPs.

In India, Dhawan *et al.*[25], working on nanotoxicology, demonstrated a strong correlation between the presence of $nC_{60}$ and DNA damage. Of late, nanotoxicology has become a special research enquiry to address the question of toxicity in some of the developed countries. Lewenstein[26] raises the following questions about the risk: who is likely to bear the risks of any environmental challenges – investigators, workers or communities near the manufacturing plants? Who will reap the benefits of environment-friendly materials – producers, consumers, or anyone who breathes the air and drinks the water? How will decisions about costs and benefits be made, and by whom? These questions are important in making judgments about acceptable level of risk. Winner[27], while raising several issues and questions regarding social impact of nanoscience and nanotechnology, asks who gets to define what the transformation of the society will involve? These questions relate to the governance of risk.

The general case for wider societal dialogue about novel technologies, and with it greater openness about science policy, rests upon three broad sets of argument. Fiorino[28] characterizes these as normative, instrumental and substantive. The normative argument proposes that dialogue is a good thing in and of itself, and as such forms a part of the wider democratic processes through which controversial decisions are made. The instrumental argument suggests that dialogue, as one means of rendering decision-making more open and transparent, will increase the legitimacy of decisions. Finally, the substantive argument is that dialogue will help generate better quality outcomes. The need for a dialogue involving stakeholders – scientists, technologists, industry representatives, policy makers and civil society regarding nanoscience and nanotechnology is desirable to address the ethical and value concerns of the society at large.

## Regulatory mechanisms

### *Risks and the need for regulation*

We have mentioned earlier the probable and possible risks associated with nanotechnology. Regulation of nanoscience and nanotechnology to minimize risk in developing countries like India is important because of social amplification of risk, as mentioned above. Burgi and Pradeep[4] claim that it is too early to develop any mistrust about nanotechnology[4]. But when it is too early to give an opinion about the negative social effects, the parity of reasoning suggests that it may also be too early to highlight the as yet untested positive social effects of the technology. We can analyse implications of nanoscience and nanotechnology by comparing and contrasting it with another developed technology in the recent history – genetic engineering technology.

Let us take the example of genetically modified seeds, especially adoption of *Bt* cotton in India. The company claimed that the *Bt* cotton seed would protect the crop against pest attacks and thus eliminate the use of pesticides and the corresponding enhancement in yield achieved by protecting the crop. However, the evidence suggests that the performance of *Bt* cotton in different states has been varied. Further, farmers continue to use pesticides to tackle secondary pests. There are various apprehensions and these have made the introduction of genetically modified crops impossible, as there was no dialogue among the stakeholders regarding the genetically modified crops. Adoption of nanoscience and nanotechnology should not follow the same trajectory.

Do we need any regulatory body in India to regulate nanoscience and nanotechnology R&D? We will partly address this question by citing an example regarding the use of helmet by motorbike riders. One does not use the helmet because he/she is certain that he/she is going to meet with an accident. People are advised to use helmets to minimize risk. Hence the use of helmet is mandatory while riding a bike under the law. Here, the government is acting both as the norm authority and the regulatory body. Analogically it may be argued that there is a need for regulation of nanoscience and nanotechnology research.

We can envisage generally three kinds of situations in relation to regulation in the context of research in developing new technologies: First, where one needs a simple permission, which is a lack of prohibition, to carry out research in a particular manner. In this situation, the norm authority does not impose any restriction at any stage of the research. The second situation is that of informed permission, where there will be a properly constituted regulatory body constitutive of members from natural sciences, social sciences, ethics and law. The members with their expertise in various fields regulate the path of development of a particular technology. And the third kind is a situation which lies between the two situations already mentioned. Here, there is need for regulation at a certain stage of the research when a new thing may be expected to create some ill-effect on the environment or society. We will present responses of scientists to the question of regulation of nanoscience and nanotechnology research in India, based on interviews with those engaged in nanoscience and nanotechnology research in the country.

In India, often the majority of scientists articulate the need for complete freedom in pursuing their scientific research and expect that there should not be any kind of prohibition at any stage of research by the norm authority. This can be understood as a case of simple permission. We quote the response of a practising scientist in India, when he was asked if one needed a regulatory body in the country for nanoscience and nanotechnology:

> Science will grow on its own. When electric bulb came out there were also oppositions in the society. But now we are able to work at nights. Similarly, nanotechnology will be good for the society. We can do many things at nano level which will be good for the society. So we do not need a regulatory body.

The argument of the scientist assumes that the analogy between any nanoscience and nanotechnology product and electric bulb technology is a valid one. It then goes on to claim that since the electric-bulb technology was created without the requirement of any informed permission of a regulatory body, no nanoscience and nanotechnology research should be guided by informed permission. The weakness of this argument stems primarily from the shaky analogy between electric bulb technology and nanoscience and nanotechnology product-oriented research, and from conflating all cases of permission to be cases of simple permission, especially in the context of research.

In the second situation, some practising scientists in India do think that one needs a regulatory body in India for nanoscience and nanotechnology research. To quote a scientist working in the area of nanoscience and nanotechnology:

> Yes, definitely. When it comes to health concern or impact on society, definitely yes. There should be some regulatory body or public health institutions or this could be a part of national initiative. They [reviewers] are monitoring from scientific point of view. It is interdisciplinary, neither purely science, nor purely health. [There] has to be [a] synergy between the two.

The above statement reflects the socio-cultural perspective on risk according to which lay persons' view on risk should be taken into consideration while assessing the risk. This perspective on risk claims that since the lay persons handle real-life situations where they are faced with risk, their life experiences and views should also be factored into the scientists' assessment of risk. In order to assess the risk and regulate nanoscience and nanotechnology research one needs informed permission, which amounts to restricting certain freedom at a certain point of time of the scientific research. Here the notion of risk to health and environment can be understood in relation to two types of consequences, namely probable and possible consequences. In the first type, there is a finite (may be small) likelihood of the risk being real. For example, as we have already mentioned earlier, asbestos particles resemble nanoparticles in size. So, there is a higher probability that nanoparticles might cause harm to human health like that caused by asbestos particles. In the second type, the risk might become real in the long run.

The third position is taken by a group of scientists who advocate for a simple permission at the early stage of research before it becomes a case of an informed permission. Here one does not know at what stage of research there would be a need for a regulatory body. To quote a scientist's response to the question on the need for an agency to regulate nanoscience and nanotechnology research in India:

> Not right now. At this point in time none of these [regulatory] actions should contain the growth of science. Nano is in its infancy. All that I would advocate at this point in time is awareness. Once our society is prepared, if research takes [us] that far, we may think of regulations.

This reflects that some of the scientists working in the area of nanoscience and nanotechnology in India are aware of the risks associated with it. But clearly they do not advocate regulation at the present stage of research, as it may slow down or halt the pace. This view implies that regulation can wait till there are some visible consequences for the society.

Science research is underwritten by society, and therefore, no research is completely free from some kind of monitoring. Presently in India we have a committee of scientists to decide the direction or thrust areas of nanoscience and nanotechnology research in the country. This committee must be expanded to include members drawn from different disciplines to monitor or set the path for the development of nanoscience and nanotechnology. Such a committee should visualize possible harms instead of actual or even probable harms that nanoscience and nanotechnology will create. Chowdhury[29] advocates the regulatory measures to prevent hazards and ensure the safe use of the technology.

As mentioned earlier, some of the Western countries have already developed a special branch of enquiry like nanotoxicology. Some Indian scientists are in favour of institutionalizing that sub-specialty. To quote a scientist working at one of the IITs:

> Nanotoxicology is an area which is coming up. This area is happening in India too. We have to evaluate the impact of any material before that is taken to the people who are going to use it. To evaluate the impact of this, nanotoxicology studies are necessary.

In India, awareness based on research has yet to be created in a systematic way. Since India is a veritable land of diversity in terms of social groups such as castes, religions, culture, food and dress habits, nanoscience and nanotechnology is likely to have multi-layered effects in an uneven way. As in the case of any other technology, some of the questions regarding nanoscience and nanotechnology that are pertinent in the Indian context are: will the R&D efforts in nanoscience and nanotechnology in India produce novel products based on nanoscience that are relevant and useful to Indian agriculture and health care? To what extent will the technology be accessible to all sections of the society? To what extent will the benefits be equitably distributed? How do we manage risk? These questions, related to larger issues of equity and justice, have to be addressed. It is in this context that social science research assumes significance as it focuses on the ELSE issues involved in the generation and application of technologies. The literature on ELSE issues suggests that the potential of social science research to address these issues is recognized to a greater extent in the Western countries than in the developing countries.

## Conclusion

Nanoscience and nanotechnology, like any other knowledge and associated practices that were developed in the past, is getting shaped by scientific, technological, economic and cultural forces. Different sections – enthusiasts and skeptics – of this new technology are engaged in a debate about the degree of desirability of this technology from different value-premises and interpretations of the new technoscience. In the Western countries research on ELSE dimensions of nanoscience and nanotechnology has been recognized as a legitimate field of inquiry. Research on social, economic, environmental and health effects of nanoscience and nanotechnology, and risks associated with this new technology and regulatory norms have been initiated with adequate funding. In India, similar evaluations of nanoscience and nanotechnology have not been taken up yet. The nanoscience and nanotechnology community in India, except a few members, does not seem to appreciate the ELSE issues relating to nanotechnology adequately. The nanoscience and nanotechnology community seems to put relatively greater emphasis on economic benefits than on social and environmental implications of nanoscience and nanotechnology. Interdisciplinary research involving natural sciences and social sciences with a dispassionate spirit of inquiry that characterizes the ethos of science would provide insights relevant for policy–practice dynamics.

In order to gain the trust of the public and for better regulation of the technology and following Fiorino's schema of various kinds of arguments, issues like risks and ethics have to be debated and a consensus has to be arrived at in the context of the development of nanoscience and nanotechnology in India. Although in India research in the area of nanoscience and nanotechnology had started fifteen years ago, till now there is no significant study conducted in the area of social, cultural, ethical and environmental implications of nanotechnology. Other countries, like the US, have already started spending for environmental and health implications research. For example, in 2004 the federal funding accounted for US$ 8.5 million and in 2006 it became US$ 38.5 million[21]. Therefore, we believe that the need of the hour is to conduct studies on the ELSE issues of nanoscience and nanotechnology in India, objectively. These studies may be useful to build approximate scenarios on the basis of different sets of assumptions about the nature of nanoscience and nanotechnology and the related ELSE issues. Given the far-reaching implications, there is also a need to establish a broad-based, transparent regulatory body which will take into account research inputs drawn from several scientific disciplines, including social sciences. It is worthwhile to create a research cell in the nanoscience and nanotechnology mission (Nanomission) that addresses the ELSE issues and earmarks funding for research on them.


1. MacKenzie, D. and Wajcman, J., *Social Shaping of Technology*, Open University Press, Buckingham, 1999, 2nd edn.
2. Bijker, W. E., Hughes, T. P. and Pinch, T. J. (eds), *The Social Construction of Technological Systems: New Directions in the Sociology and History of Technology*, MIT Press, Cambridge, 1987.
3. Nelkin, D., 'Science controversies: the dynamics of public disputes in the United States'. In *Handbook of Science and Technology Studies* (eds Jasanoff, S. *et al.*), Sage Publication, London, 1995, pp. 444–456.
4. Burgi R. B. and Pradeep, T., Social implications of nanoscience and nanotechnology in developing countries. *Curr. Sci.*, 2006, **90**, 645–658.
5. Feynman, R., There's plenty of room at the bottom, 1959; www.its.caltech.edu
6. Drexler, K. E., *Engines of Creation: The Coming Era of Nanotechnology*, Anchor Books, USA, 1986.
7. McCray, W. P., Will small be beautiful? Making policies for our nanotech future. *Hist. Technol.*, 2005, **21**, 177–203.
8. Roco, M. C. and Bainbridge, W. S., Societal implications of nanoscience and nanotechnology. Report of the National Nanotechnology Initiative Workshop, 3–5 December 2003, Washington DC, 2005.
9. Singer, P., Salamanca-Buentello, F. and Daar, A. S., Harnessing nanotechnology to improve global equity. *PLoS Med*., 2005, **2**,
10. Kalam, A. P. J., quoted in Stuart, C., India sees growth through nanotech. *Small Times,* 2006, http://stm.dev.pennnet.com/articles/article_display.cfm?Section=ARCHI&C=Finan&ARTICLE_ID=269635&p=109
11. These include the Institute of Smart Materials, Structures and Systems of the Indian Institute of Science, Bangalore; Jawaharlal Nehru Centre for Advanced Scientific Research, Bangalore; Indian Institutes of Technology at Delhi, Chennai, Kharagpur, Mumbai and Roorkee; Saha Institute of Nuclear Physics, Kolkata; University of Hyderabad; University of Pune; University of Delhi; National Chemical Laboratory, Pune; Tata Institute of Fundamental Research, Mumbai; National Physical Laboratory, New Delhi; Solid State Physics Laboratory, Delhi; Central Electro Chemical Research Institute, Karaikudi; Indian Association for the Cultivation of Science, Kolkata; Bhabha Atomic Research Centre, Mumbai, etc. Among the industries are: Amity Institute of Nanotechnology, New Delhi; Centre for Cellular and Molecular Biology, Hyderabad; Indian Petrochemicals Corporation Limited, Vadodara; Indiaco Innovation Centre, Pune; C-MET, Pune; Qtech Nanosystems, Bangalore; Velbionanotech, Bangalore; Nano Science and Technology Consortium, Noida; Nanoxtals, Delhi, etc.
12. Drexler, E., quoted in Wood, S., Jones, R. and Geldart, A., The social and economic challenges of nanotechnology, ESRC Report, UK, 2002, p. 114.
13. Joy, B., Why the future doesn't need us. *Wired*, 2000, issue 8.04; http://www.wired.com/wired/archive/8.04/joy.html
14. Smalley, R., quoted in Wood, S., Jones, R. and Geldart, A., The social and economic challenges of nanotechnology, ESRC Report, UK, 2002, p. 27.
15. Ball, P., quoted in Wood, S., Jones, R. and Geldart, A., The social and economic challenges of nanotechnology, ESRC Report, UK, 2002, p. 27.
16. Adam, B., Beck, U. and Van Loon, J., *The Risk Society and Beyond: Critical Issues for Social Theory*, Sage Publications, London, 2000.
17. Douglas, M. and Wildavsky, A., *Risk and Culture: An Essay on the Selection of Technological and Environmental Dangers*, University of California Press, Berkeley, 1980.
18. Pidgeon, N., Kasperson, R. E. and Slovic, P. (eds), *Social Amplification of Risk*, Cambridge University Press, Cambridge, 2003.
19. Barbour, I. G., *Technology, Environment and Human Values*, Praeger, New York, 1980.
20. Balbus, J., Denison, R., Florini, K. and Lash, S., Getting nanotechnology right the first time. In *Nanotechnology: Risk, Ethics and Law* (eds Hunt, G. and Mehta, M. D.), Earthscan, London, 2006, pp. 130–139.
21. Royal Academy of Engineering and Royal Society, *Nanoscience and Nanotechnologies: Opportunities and Uncertainties*, London, 2004.
22. Oberdorster, E., Fullerenes and fish brains. *Environ. Health Perspect.*, 2004, **112**, A568.
23. Nel, A., Xia, T., Mädler, L. and Li, N., Toxic potential of materials at the nanolevel. *Science*, 2006, **311**, 622–627.
24. Oberdorster, G., Oberdorster, E. and Oberdorster, J., Nanotoxicology: an emerging discipline evolving from studies of ultrafine particles. *Environ. Health Perspect*., 2005, **113**, 823–838.
25. Dhawan, A., Taurozzi, J. S., Pandey, A. K., Shan, W., Miller, S. M., Hashsham, S. A. and Tarabara, V. V., Stable colloidal dispersions of $C_{60}$ fullerenes in water: evidence for genotoxicity. *Environ. Sci. Technol.*, 2006, **40**, 7394–7401.
26. Lewenstein, B. V., What counts as a social and ethical issue in nanotechnology? *HYLE – Int. J. Philos. Chem.*, 2005, **11**, 5–18.
27. Winner, L., Testimony to the Committee on Science of the US House of Representatives on the Societal Implications of Nanotechnology, 2003.
28. Fiorino, D. J., Citizen participation and environmental risk: A survey of institutional mechanisms. *Sci. Technol. Human Values*, 1990, **15**, 226–243.
29. Chowdhury, N., Regulatory supervision of emerging technologies – A case for nanotechnology in India. *Econ. Political Wkly*, 2006, **41**, 4730–4733.


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