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Nanotechnology to Nanomanufacturing: Emerging Models

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1.0 Introduction

Science and technology are seen as important determinants for survival and growth of companies, regions and nations (Schumpter,1934) and are related to new theories of economic development, technological change and industrial innovation.(Dosi et al 1990;Romer 1990). In order to reach technology based economic growth, it is not only necessary to invest capital, intellect and time in science and technology-related research and development(R&D), but also to execute pressures related to diffusion, adoption and implementation of technology based innovations. Additionally, disruptive technologies as the counterpart of technologies with an incremental innovation effect -form important fundamentals for growth innovations and related wealth creation (Kassicrieh et al 2002). Nanotechnology is recognized as a promising new growth innovator for the decades to come (Wolde, 1998; Roco, 2001; Paull et al 2003).It is mostly developed in knowledge intensive organizations (eg, Universities or Company R&D laboratories) strongly focused on the science and technology part of nanotechnology.

However from the growth perspective it is important to facilitate the ability to exploit the innovative and added value of nanotechnology into applications. This means that nanotechnology knowledge generated in knowledge intensive organizations need to be transformed and/or transferred in order to design, produce, sell, adopt and implement nanotechnology-based customer oriented applications. The innovation development process are organizational level from R&D to invention to market ready applications is not linear, but a cyclic process with parallel and iterative loops (Kline and Rosenberg, 1986; Rothovell, 1992; Tidd et al , 2001). With respect to disruptive technologies like nanotechnology, Walsh, 2004 presents an infrastructure model that points out the dynamics between technology push side and market pull side in the innovation development process. Nanotechnology as disruptive technology can lead to next generation (initially unknown) markets. This gives additional dimensions and challenges to innovative processes covering development and commercialization of nanotechnology in an international market arena, especially for small nanotechnology firms.

2.0 Disruptive aspects of Nanotechnology

Nanotechnology and dynamic international market manipulating atoms arrangements is the basis of nanotechnology and ideas in this field were first communicated by physicist Feyman (1959).Nanotechnology according to Roco 1999 is concerned with development and utilisation of structures and devices with organizational features at the immediate scale between individual molecules and about 100 nanometers where novel properties occur as compared to bulk materials. These nanoscale structures and devices may have unique chemical, electrical, magnetic, optical or biological properties. At the junction of Chemistry, Physics, Biology, Computer Science and Engineering, Nanotechnology embeds nanoscience insight in order to fabricate new materials, structures or devices which exploits nanoscale properties. The nature of nanotechnology is strong multidisciplinary and Hullman and Meyer (2003) show this via the range of scientific disciplines nanotechnology publications and nanotechnology patent covers. Some discipline examples for instance are material science, polymer science, electrical and electronic engineering, Optics, biophysics, organic chemistry or cell biology. The patent data suggests that the core activities of nanotechnology focus on electronics, instrumentation, and chemicals/pharmaceuticals. Besides this conclusion based on patent data, Bhat 2003 sees the following industries likely to be immediately affectedbynanotechnology,aerospace,automotive,biotechnology,ceramics,chemicals, computing, defence, electronics, metals, materials, paper, plastics, renewable energy, textiles and telecommunications.

Nanotechnology as a cluster of new technologies undergoes typical patterns of scientific, technological and economic developments. First nanoscience has lead to a strong-scientific push and resulted in a dramatic increase of scientific publications and patents on nanotechnology. (Compano and Hullmann, 2002; Hullman and Meyer, 2003; Marinova and McAleer, 2003; Roco, 2003). Additionally, the technology-pull has emerged in order to use and transform nanoscience in order to use and transform nanoscience knowledge into technologies. Lately a premature market-pull era has been initiated which stimulates the use of nanotechnology in applications in order to create innovations. In this phase, companies are actually producing and selling nanotechnology based applications. On the other hand, Mazzola 2003, points out that many nanotechnology applications are still at concept level, requiring much more basic research before they can be incorporated into viable applications. Related to the typical; Sigmoidal curve of innovation diffusion (Rogers,1995) nanotechnology is just about in the so-called “take-off phase”.

3.0 Nanoscale manufacturing : converting nanoscience into new technologies

Turning the promise of nanoscience into new technologies is one of the biggest challenges that face the research community today. The bottleneck is the lack of technologies for manufacturing nanostructures and nanomaterials in large quantity and at low cost. Research in nanomanufacturing is focused on developing optical based, low cost, massively parallel manufacturing techniques. Specifically, a type of nanostructure, called nanoscale optical antenna is developed to concentrate energy of light into a nanoscale domain, and is being used for nanomanufacturing purpose. This involves researches in several disciplines, including manufacturing Science and engineering, control, radiation, optics and mechanics. Nanomanufacturing is both the production of nanoscaled materials, which can be powders or fluids, and the manufacturing of parts “bottom up” from nanoscaled materials or “top down” in smallest steps for high precision, used in several technologies such as laser ablation, etching and others. Nanomanufacturing involves scaled up, reliable and cost effective manufacturing of nanoscale materials, structures, devices and systems. It also includes research, development, and integration of top down processes and increasingly complex bottom up or self assembly processes.

Within the top-down and bottom-up categories of nanomanufacturing, there are growing number of new procecesses that enable manufacturing. Among these are:- Chemical vapor deposition-is a process in which chemicals react to produce very pure, high performance films.; Molecular Beam Epitaxy -is one method for depositing highly controlled thin films.; Atomic layer epitaxy-is a process for depositing one atom-thick layers on a surface.; Dip pen lithography-is a process in which the tip of an atomic force microscope is “dipped” into a chemical fluid and then used to “write “ on a surface, like an old fashioned ink pen into paper.; Nanoimprint lithography-is a process for creating nanoscale features by “stamping” or “printing “them on to a surface.; Roll- to- roll processing-is a high volume process to produce nanoscale devices on a roll of ultrathin plastic or metal.; Self-assembly describes the process in which a group components come together to form an ordered structure without outside direction. Structures and properties of materials can be improved through these manufacturing processes. Such nanomaterials can be stronger, lighter, more durable, water repellent, anti-reflective, self cleaning, ultraviolet or infrared resistant, antifog, antimicrobial, scratch resistant or electrically conducive among other traits. Taking advantage of these properties, today's nanotechnology enabled products range from basketball bats and tennis rackets to catalysts for refining crude oil and ultrasensitive detection & identification of biological and chemical toxins. Although industries and applications are or will be influenced by nanotechnology, Bhat 2003 argues that the mentioned multidisciplinary nature of nanotechnology makes it very difficult to pin down and prophery the future impact in any scientific sector appropriately.

This is a major reason why nanotechology is mostly seen as a disruptive technology. According to Brower and Christensen 1995,a technology is considered disruptive when its utilisation generates products with different performance attributes that may not have been valued by existing customers. In case of nanotechnology-this means that it has the ability to influence enhanced or new nanotechnology-enabled products, services or processes for existing or new markets. For a few years now, nanotechnology has been recognized as a promising new growth innovator. This leads to a shift from the exploration of nanotechnology knowledge towards a phase of exploitation. Nanotechnology is a disruptive technology phenomenon. Nanoscale transistors may lead to Computers that are faster, more powerful, and more energy efficient than those used today. Nanotechnology also holds the potential to exponentially increase information storage capacity-soon the computer's entire memory will be able to be stored in a single tiny chips. In the energy arena, nanotechnology will enable high efficiency, low cost batteries and solar cells.

4.0 Micro & nanomanufacturing as a strategic Industrial sector

The increasing drive towards miniaturization has dictated the new micro-and nano-manufacturing technologies which are developed in parallel with nanotechnology, molecular engineering and biotechnology in order to keep abreast of future technological developments. The demands of the 21st century Society for solutions of the “grand challenges” for an ever improving yet affordable healthcare, higher standards of living and quality consumer goods and the risks posed by increasing energy costs and depleting resources are still unanswered. These technologies will lead to higher energy costs in early development stages due to current processing technology. At the same time, advanced micro and nanofabrication are exciting from the aspect that fewer energy and resources will be consumed once these technologies mature. For example, they will lead to scrap reduction and less waste due to build up process versus removal of material to obtain the end product. Nanomanufacturing technologies are already being developed to reduce dependence on fossil fuels and consequently reduce the carbon-dioxide emissions, as well as reduce the concentration of nitrogen oxide and sulphur oxide in the atmosphere. Areas where nanomanufacturing technologies may provide environmental benefit: electricity storage, thermovoltaics, fuel cells, lighting, engine/fuel efficiency, weight reduction of materials. Microsystems, sensors and actuators are consolidating their position in established markets and finding new applications, leveraging a combination of advantages ranging from low manufacturing costs, compact size, low weight and power consumption, as well as increased intelligence and multifunctionality. Europe already assumes an outstanding position due to its well developed technical innovativeness and industrial exploitation of new technologies (micro, nano, opto, bio).There has been growing trend in development and innovation capacities in Europe.

4.1 Electricity Storage: improved efficiency of conventional rechargeable batteries which could be used in transport applications to reduce emissions or as back up for alternative energy to allow very high levels of renewable energy. Nanotechnologies are likely to be employed in developing supercapacitors, which provide alternative methods of electricity storage.

4.2 Thermovoltaics: new nanomaterials which turn waste heat into electricity. This could result in significant energy savings in any application where combustion is the primary method of energy generation(eg hybrid cars).

4.3 **Fuel Cells**: either as part of a sustainable hydrogen economy or as efficient hydrocarbon based fuel cell, there is potential to reduce vehicular emissions or, as CHP (Combined heat and power) plant, reduce heating and electricity generation emissions.

4.4 **Lighting**: LEDs offer an energy efficient alternative to conventional incandescent light sources. Nanotechnology is being employed to develop these new light sources.

4.5 **Engine/fuel efficiency**: the use of nanoparticulate fuel additives could reduce fuel consumption in diesel engines and improve local air quality. Micro and nanomaterials are also being used to improve the heat resistance of aeroplane turbine blocks allowing the engine to run at higher temperatures, which improves the overall engine efficiency.

4.6 **Weight reduction**: novel high strength composite materials could reduce the weight of materials. Future goals include the reduction of vehicles weight through the use of nanotubes in metal alloys and plastics; improved tyres incorporating nanoparticles in rubber formulas & optimized combustion processes in motors(nanotech catylic converters).

5.0 Nanomanufacturing Technology, International Practices and Policy Support Mechanisms

Nanotechnology has potential applications in numerous segments of the Indian economy, counting customer items, social insurance, transportation, vitality and horticulture. Moreover, nanotechnology exhibits new chances to enhance how we measure, screen, oversee, and minimize contaminants in nature's turf. A nanometer is one billionth of a meter (10-9 m) — around one hundred thousand times more small than the breadth of a human hair, a thousand times littler than a red platelet, or about a large portion of the span of the breadth of DNA. With the end goal of this archive, nanotechnology is characterized as: exploration and engineering advancement at the nuclear, sub-atomic, or macromolecular levels utilizing a length scale of pretty nearly coordinated hundred nanometers in any measurement; the creation and utilization of structures, gadgets and frameworks that have novel properties and capacities on account of their little size; and the capability to control or control matter on a nuclear scale. It is an exceptionally multidisciplinary field, uniting various fields, including electrical and mechanical outlining, material science, science, and biosciences. Nanotechnology will significantly impact all these controls and their application zones. Money related impact is expected to be comparable to information advancement and telecom business wanders.

The vision of Nokia Research Center is to transform into the overall pioneer of open headway for human convey ability systems of the consolidated physical and modernized world, considering the improvement of business for Nokia. In this paper we will give a blueprint of how nanotechnology can be utilized so as to benefit the human generation and perhaps, the Quintessential manner to approach Nanotechnology related growth. Nanotechnology is the control of matter for utilization specifically applications through certain substance and/ or physical procedures to make materials with particular properties. There are both "base up" procedures, (for example, gathering toward oneself) that make nanoscale materials from particles and atoms, and "top-down" methodologies, (for example, processing) that make nanoscale materials from their macro-scale partners. Nanoscale materials that have macro-scale partners habitually show distinctive or improved properties contrasted with the macro-scale structure. For the rest of this record such designed or made nanomaterials will be alluded to as "deliberately delivered nanomaterials," or just "nanomaterials." The meaning of nanotechnology does exclude unintentionally created nanomaterials, for example, diesel debilitate particles or other grating or airborne burning results, or nanosized materials that happen commonly in nature's domain, for example, infections or volcanic cinder. Where data from unexpectedly shaped or characteristic nanosized materials, (for example, ultrafine particulate matter) may support in the understanding of purposefully delivered nanomaterials, this data will be examined, yet the center of this archive is on deliberately created nanomaterials.

The enhanced understanding of intelligent powers among nanostructures and materials, consolidated with the ensuing aggregate conduct inside incorporated frameworks has empowered new strategies for the controlled control of nanocomponents and structures containing a more extensive order. As being what is indicated, this new understanding will turn into a focal research subject for revelations and advancements to new advertisement applications, alongside new standards in assembling sciences to address the vital economy of scale necessities for these new items. Coordinated frameworks nanomanufacturing must consolidate the understanding that has advanced to accomplish this controlled control of materials and structures with rising capacities and strategies to acknowledge new aggregate usefulness for cutting edge frameworks. Now we would share some of the developments in the field of Nanotechnology which is on its way to production and distribution.

5.1 Bimolecular

MEMS and Nanotechnology have enabled label-free and scalable detection of biologically significant molecules such as DNA, RNA, proteins and small molecules whose detection in small quantities is of paramount importance for early disease diagnostics. Current research areas include: 1) development of nanomechanical and optical biosensors and their application to detection of a variety of proteins including cancer markers 2) novel receptor molecules and their integration into biosensing, 3) biosensing using nanoparticles, 4) rapid detection of pathogens and 5) sensitivity enhancement of biosensors. The work is currently supported by NSF and NASA.

5.2 Micro and Nano-Fluidics

Research in the micro fluidics laboratory is concentrated in two primary areas: experimental fluid dynamics in micro/nano domains and micro-fabricating novel micro fluidic devices. Ongoing projects include fundamental biology (response of live cells to flow stresses, below right), fundamental fluid mechanics (characterizing microscopic supersonic flows, below left; nanoparticles flow dynamics), and characterizing biomedical micro-devices. Currently the Micro fluidics laboratory is supported by the NSF (Ocean Biology and Nanoscale Science and Engineering), DOD (Crane-NSWC), SOI.

5.3 Computational Nanotechnology

Numerical simulation plays a critical role in exploring novel nanoscale structures, materials, devices and systems. Research in this area is focused on the development of physical models and computational methodologies to address a number of areas including emerging micro- and nanoelectronics, phase-change memory technologies, ultra-fast laser manufacturing, as well as the fundamentals of nanoscale thermal and fluid transport. Computational techniques include novel finite volume techniques for the phonon Boltzmann transport equation, molecular dynamics techniques, as well as multiscale methods spanning micro, meso and macro scales. Research in this area is supported by NSF, the state of Indiana and the electronics industry.

5.4 Nanoscale Manufacturing

Turning the promise of nanoscience into new technologies is one of the biggest challenges that face the research community today. The bottleneck is the lack of technologies for manufacturing nanostructures and nanomaterials in large quantity and at low cost. Research in nano-manufacturing is focused on developing optical based, low cost, massively parallel manufacturing techniques. Specifically, a type of nanostructure, called nanoscale optical antenna is developed to concentrate energy of light into a nanoscale domain, and is being used for nanomanufacturing purpose. This program involves researches in several disciplines, including manufacturing science and engineering, control, radiation, optics, and mechanics. It is currently supported by NSF, ONR, and NASA.

5.5 Nanoscale Theramal-Electrical Transport

The interplay between thermal and electrical energy at small scales can strongly influence the functional behavior of many types of devices such as direct energy conversion elements, heat sinks, and field-effect transistors. Research at the Nanoscale Thermo-Fluids Lab seeks to address these issues by studying novel nanomaterials, particularly carbon nanotubes, both from the perspective of material synthesis and characterization and from the perspective of functional engineering performance. The laboratory's activities include detailed experimental and computational studies synthesis by plasma-enhanced chemical vapor deposition with applications to single-wall carbon nanotubes transistors, and multi-wall carbon nanotubes arrays used to enhance thermal/electrical interface conductance, boiling heat transfer, and biosensor performance. Further, the lab has developed unique capabilities to measure and model thermal-electrical energy transport and conversion from nanoscale electron emitters. Researchers in the laboratory routinely collaborate with electrical engineers, material scientists, physicists, chemists, and biologists, and the work is supported by NSF, NASA, the Air Force Research Laboratory, the Semiconductor Research Corporation, and a variety of industrial interests.

5.6 Thermal Micro/Nanosystems

Thermal transport is becoming increasingly critical in the design and performance of micro-and nano-systems. Research in this area includes the development of a range of micropumping approaches and high-resolution measurement techniques. Representative projects include the development of a micromechanical electro hydrodynamics (MEHD) based liquid pump with multiple driving mechanisms to deliver high flow rates, and an ionic wind-driven heat transfer enhancement scheme. Other areas of research include microscale actuation of liquids using electrowetting and dielectrophoresis, thin film evaporation, single and two-phase microchannel transport and development of carbon nanotube-based heat spreaders. Research outcomes from these efforts have direct applications in providing solutions for the thermal management of microelectronics, and are supported by NSF and the State of Indiana, besides a wide range of industrial sponsors.

5.7 Nano Thermo-Physical Engineering

The behavior of any physical system can be related to atomic-scale description. With an atomic level knowledge of the energy carrier (photon, electron, phonon, and fluid particle) characteristics and behaviors, one is able to move up to design nano- and micro-structures with the desired size effects, or to synthesize new materials with the desired functions. Research at the Nano Thermo Physical Engineering Lab seeks to build and expand the understanding of the fundamentals of atomic-level carrier transport and interactions, and to apply this knowledge to important energy and information technologies. Current projects include the engineering of electron-phonon coupling in quantum dot solar cells, enhanced laser cooling of semiconductors and ion-doped solids, controlled thermal emission using modulated micro- and nano-structures, thermo-optical management of nano lasers, etc. 5.8 Advanced Micro/ Nano mechanical Materials and Process Technologies To date, materials selection capability in micro/nano systems applications has been relatively limited, due primarily to the predominance of micro fabrication processes and infrastructure dedicated to silicon. While silicon has proven to be an excellent material for many applications, no one material can meet the needs of all applications.

Research in this area, therefore, seeks to develop the materials and process technologies required for realization of applications that are either impractical or impossible using conventional silicon-based micromachining, e.g. biomedical and harsh environment applications. Areas of specific interest with this context that are currently under development include anisotropic titanium micromachining, micromechanical composites, and novel applications thereof. Focusing more on Nanomanufacturing, it is both the creation of nanoscaled materials, which can be powders or liquids, and the assembling of parts "lowest part up" from nanoscaled materials or "top down" in most modest steps for high exactness, utilized within a few advances, for example, laser removal, drawing and others. Nanomanufacturing varies from atomic assembling, which is the production of complex, nanoscale structures by method for nonbiological mechanosynthesis (and ensuing assembly). The expression "nanomanufacturing" is generally utilized, e.g. by the European Technology Platform Minam and the U.S National Nanotechnology Initiative (NNI). The NNI alludes to the sub-space of nanotechnology as one of its five "need areas." There is likewise a nanomanufacturing project at the U.S National Science Foundation, through which the National Nanomanufacturing Network (NNN) has been built.

The NNN is an association that attempts to assist the move of nanotechnologies from research center exploration to generation assembling and it does so through data exchange, key workshops, and guide advancement. The NNI has characterized nanotechnology extremely broadly, to incorporate an extensive variety of little structures, including those made by vast and uncertain devices. Nonetheless, nanomanufacturing is not characterized in the NNI's late report, Instrumentation and Metrology for Nanotechnology. Conversely, an alternate "need region," nanofabrication, is characterized as "the capacity to create, by regulated or get toward oneself together routines, utilitarian structures or gadgets at the nuclear or atomic level" . Nanomanufacturing has all the earmarks of being the close term, mechanical scale production of nanotechnology-based items, with attention on ease and unwavering quality. Numerous expert social orders have framed Nanotechnology specialized gatherings. The Society of Manufacturing Engineers, for instance, has framed a Nanomanufacturing Technical Group to both advise parts of the creating advances and to address the hierarchical and IP (intellectual property) lawful issues that must be tended to for more extensive commercialization.

5.8 Nanomanufacturing Practices & Policy Support

Indian & International: Countries all around the world are investing heavily in Nano Manufacturing related domain. In 2009, the sum total invested by Government, Corporations and Investors totalled $17.6 billion. In India, the main aim of the Nano Manufacturing technology centre is to help industries to absorb/adapt this technology and offer services in machining and measurement of Nano components and devices which would help new product development technology advancement across the country. The CMTI has also proposed to create Centre of Excellence in the field of Nanomanufacturing. The estimated cost of the project is about Rs. 280.00 Crores which requires funding support from the budget. The Nano Manufacturing Technology Centre (NMTC) and the Academy of Excellence for Advanced Manufacturing Technology (AEAMT) have come up as the Flag Ship Projects of Government of India and funded under the XI Plan by the Department of Industrial Policy & promotion (DIPP), Ministry of Commerce and Industry. In case, the US government has made many developments and is continuously taking steps to improve and enhance the development of the Nano Manufacturing Sector in the Country.

They have tied up with: Department of Energy, Industrial Technologies Protocol with Industrial Partners and National Laboratories to work on many fronts. The projects are funded by the Industrial Technologies Protocol (I.T.P.) core program and American Recovery and Reinvestment Act (A.R.R.A.). In 2010, they had come up with 31 projects in two technical areas: Concept Definition Studies (Early Stage Studies and Research and Economic Feasibility) Process Development Subjects (Enabling Processes for Nanomaterial Fabrication and Utilisation through intergovernmental tie-ups) Source: “Ranking the Nations on Nanotech. The Authority of Law,” (August 2010). It is this broadness of nanotechnology's potential that makes it fundamental to America's future intensity. Congressman Lamar Smith, executive of the House Committee on Science, Space, and Technology, accepts that American predominance in the field has colossal monetary potential and the capacity to make new employments: "it’s an amusement changer that could change and enhance Americans' day by day exists in ways we can't predict," he says. Government financing has made a difference. From 2000-13 Congress appropriated some $18 billion for nanotechnology R&D (in spite of the fact that the $1.7 billion planned for 2014 is 8% lower than two years prior). Numbers for private-division venture are harder to get, yet gauges by Lux Research, a firm of examiners, recommend that by 2010, America's private part was contributing in any event $3.5 billion a year in nanotechnology-related wanders significantly more than its closest worldwide rivals.

6.0 Sustainable Nanomanufacturing: Creating Industries of the Future

The objective is to establish manufacturing technologies for economical and sustainable integration of nanoscale building blocks into complex, large scale systems. Thrust Area(s):- a. Design of scalable and sustainable nanomaterials, components, devices and processes b. Nanomanufacturing measurement technologies Initial focus areas will include manufactured products based on carbon based nanomaterials cellulosic nanomaterials, optical nanomaterials etc....... Production must be scalable to the required throughput and yield. The generation, manipulation and organization of nanostructures must be accomplished in a precise, controlled and sustainable manner. All nanotechnology based products must perform to specification over their entire lifetimes without the release of harmful nanomaterials or other toxic substances into the environment.

7.0 Capability, Governance and Nanotechnology developments: A focus on India

The nanoscience and technology initiative (NSTI) that functioned from 2001-2006 led by the DST was largest initiative on nanotechnology in terms of funding and implementation. It was launched with an initial budget of Rs 100 crores (approximately US $ 15-20 million).The Government in 2006-2007 approved the launch of the NanoScience and Technology Mission with a budget of Rs 1000 Crore (approx US $ 254 million) for a 5 year duration (2007-2012). Aside from funding R&D a large part of the nanotechnology budget during the NSTI appears have been spent on developing the various centers of excellence and establishing laboratory infrastructure. DIT on the other hand has spent Rs 40 crore in the years 2004-2005 and 2005-2006 and Rs 32-37 crores in 2006-2007 on its microelectronics and nanotechnology development program respectively. Budget 2007-2008(Rs 29 crores); Budget 2008-2009(Rs 33 crores). A JOINT Center for nanoelectronics at IISc Banglore and IIT Mumbai was sanctioned Rs 99.8 crores for 5 years while the development of nanotechnology at NPL was sanctioned around Rs 11 crore. CSIR is also considered to have invested approx Rs 40 crores. Since nanotechnology covers a breadth of disciplines and also is a cost intensive technology in terms of material and infrastructure needed to support research, large initial investments will be necessitated to build capacity in their arenas. Since India desires to be on par with developed nations in nanotechnology to the extent possible the large investments in the global arena has resulted in a spillover effect in India. Simultaneously, the upsurge in the Indian Scientific Community's interest in conducting nanoR&D as well as their vocal emphasis on the need to augment budgets culminated into policy makers rethinking the earlier funding frameworks.

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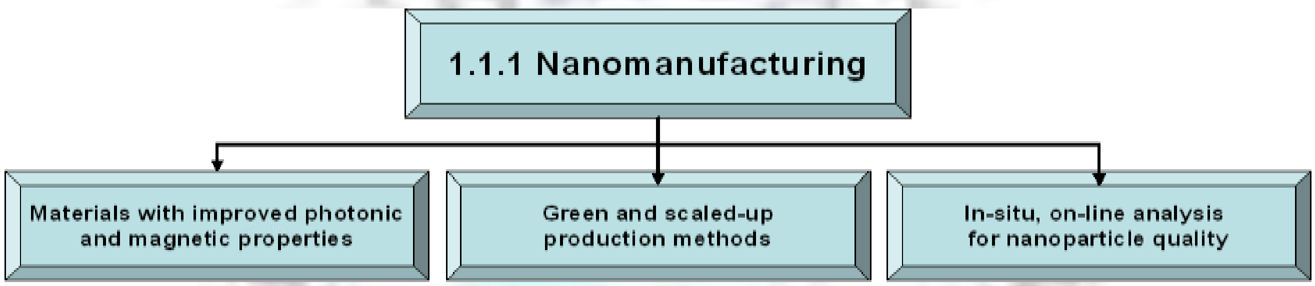

Box 4.1 Estimated timeframes for developments in nanomanufacturing

Short term (next 5 years): opportunities will arrive through the exploitation of equipment capable of imaging, analysing and fabricating simple materials and devices at the nanoscale.

Medium term (5–15 years): nanoscience and technology will give rise to nanomanufacture-by-design, using self-assembly and directed assembly methodologies to create a sustainable knowledge-based industry capable of addressing simple bio–info–nano material needs.

Longer term: it is hoped that the idea of nanomanufacturing will encompass genuine 'green' concepts of zero waste and little or no solvent use incorporating life cycle (sometimes referred to as 'cradle to grave') concepts of responsible products coupling biology with inorganic materials.