Chapter 2
Diffusion of Nanotechnology and the External Environment

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2.1 Introduction

The interdisciplinary nature of nanotechnology is a given, i.e., the principles of this technology finds its application in a variety of different sectors. Hence, its success in terms of enabling economic growth is largely dependent as to whether such collaboration at the research and development stages is promoted effectively. In fact, the celebrated multiplier effect of this technology requires collaboration without which the impact of nanotechnology would stand as irrelevant to the economic environment it is brought in.

There are a variety of different approaches to cultivate this industry across different countries. In the first section we first list the possible implications of nanotechnology on several industries such as the agriculture and the food industry, the water management industry, energy industry, solar energy industry, medicine and healthcare industries, textiles, chemicals, space, construction, electronics, automobiles, computers, and materials industries. In the second and third sections, respectively, we exemplify as to what type of policies can help this diffusion and the resulting multiplier effect. In the third section, we talk about the policy needs to advance this technology so that its applications fulfill their potential.

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N. Aydogan-Duda (ed.), *Making It to the Forefront: Nanotechnology—A Developing Country Perspective*, Innovation, Technology, and Knowledge Management 14,
DOI 10.1007/978-1-4614-1545-9_2,

2.2 The Impact of Nanotechnology on Other Industries: The Multiplier Effect

Nanotechnology is described as general purpose technology because it has implications on a variety of products and processes that can increase productivity for the general economy. The possible adverse effects of this industry are accounted for and talked about by Cozzens in Chap. 13.

Below we give a list of possible implications of nanotechnology on a variety of industries. The variety of possible applications is paramount and appears as endless. The information below is taken from the Web site of SAiNSCE (strategic applications integrating nano-science Incorporation) (http://www.sainsce.com/Default.aspx), which is a company that aims to enlarge and exploit the technological and market potential of NanoScience.

We also employ the site http://www.understandingnano.com/nanotech-applications.html and a report prepared by Kyungchee Choi of UNESCO (2005). We believe that the list is as comprehensive as it can be, but it may not be complete as everyday new applications of nanotechnology are being discovered.

2.2.1 Agriculture and Food Industries

Major challenges	What do the applications of nanotechnology offer?
Food security	Use of nanotechnology in agriculture and food industry can revolutionize the sector with new tools for disease detection, targeted treatment, enhancing the ability of plants to absorb nutrients, fight diseases, and withstand environmental pressures and effective systems for processing, storage, and packaging
Low productivity in cultivable areas	Precision farming—Nanotech application here makes farming more targeted and scientific. Precision farming makes use of computers, global satellite positioning systems, and remote sensing devices to measure various parameters. Accurate information through applications of nanotechnology for real-time monitoring of soil conditions, environmental changes and diseases, and plant health issues
Large uncultivable areas	Bringing more areas under cultivation by nanotech-enabled environmental monitoring and management including cost-effective water management through applications of nanoscience. Use of nanotechnology in agriculture can thus change the land use pattern substantially
Shrinkage of cultivable lands	The remedy is to enhance productivity through nanotech-driven precision farming and to maximize the output and minimize inputs through better monitoring and targeted action

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Major challenges	What do the applications of nanotechnology offer?
Input waste	Nanotech-enabled sensors and smart delivery systems will help the agricultural industry combat viruses and other crop pathogens In the near future, nanostructured catalysts will be available which will increase the efficiency of pesticides and herbicides, allowing lower doses to be used
Product waste	Precision farming through use of nanotech applications can also help to reduce agricultural waste and thus keep environmental pollution to a minimum
Perishability/low shelf life	Use of nanotechnology in sensing applications will ensure food safety and security, as well as technology applications which alert the customers and shopkeepers when a food is nearing the end of its shelf life. Nanotech-based new antimicrobial coatings and dirt repellent plastic bags are a remarkable improvement in ensuring the safety and security of packaged food
Technology limitations	Various devices designed through application of nanotechnology, which include biosensor for the detection of pesticides, herbicides, insecticide, viruses, microbe, will bridge this gap to a great extent. Smart packaging developed by applying nanoscience concepts and technology would be able to repair small holes/tears, respond to environmental conditions (e.g., temperature and moisture changes), and alert the customer if the food is contaminated. Food companies will have to be very vigilant in logistics
Skill limitations	Nanotechnology applications have the potential to produce easy-to-handle devices which reduce the dependence on human skills on many fronts, thus reducing the human risk. Fresh and processed food companies will have a new dimension to quality and production
Processing limitations	Nanotechnology will change the existing system of food processing and will enhance the nutritional quality of food and will ensure the safety of food products Other strategic applications of nanotechnology for use in agriculture and food processing industry include the addition of nanoparticles to existing foods to enable increased absorption of nutrients This is possible through selected additives and improvements to the way the body digests and absorbs food Nanotechnology is already making an impact on the development of functional or interactive foods, which respond to the body's requirements and can deliver nutrients more efficiently Research is on to develop new nanotech-driven "on demand" foods, which will remain dormant in the body and deliver nutrients to cells when needed. This is possible by application of nanoscience. The food companies are keen to adapt new technology in a big way

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Major challenges	What do the applications of nanotechnology offer?
Packaging limitations	Silver nanoparticles can be embedded in polymeric materials such as PVC, PE, PET while polymerization occurs. Silver nanoparticles kill pathogens, bacteria, viruses, and fungus and are used as a good and safe packaging pot. Such nanotech-based packaging materials are 100 times more secure than the normal one for the storage of juices, milk, and other agri-products. Nanotech products in packaging food products thus offer immense potential. Food packaging films in the name of "hybrid system" films have enormous number of silicate nanoparticles. They massively reduce the entrance of oxygen and other gases, and the exit of moisture, thus preventing food from spoiling or drying. Nanotechnology can provide solutions for modifying the permeation behavior of foils, increasing barrier properties (mechanical, thermal, chemical, and microbial), and improving mechanical and heat-resistance properties
	Other nanotech devices may include developing active antimicrobial and antifungal surfaces and sensing as well as signaling microbiological and biochemical changes
Diseases and calamities	The union of biotechnology and nanotechnology in sensors will create equipment of increased sensitivity, allowing an earlier response to environmental changes and diseases
Impact on environment	Nanotechnology will also help protect the environment indirectly through the use of alternative (renewable) energy supplies, and filters or catalysts to reduce pollution and clean-up existing pollutants
	Nanotech research also aims to make plants use water, pesticides, and fertilizers more efficiently
	This Nanotech application will help to reduce pollution and to make agriculture more environmentally friendly
	Thus, the use of nanotechnology in agriculture will lead to a real breakthrough in this sector

2.2.2 Water Management Industry

Major challenges	What do the applications of nanotechnology offer?
Providing clean and safe water devoid of virus, bacteria, and other elements which the conventional methods cannot tackle	Filtration via nanomembranes would ensure much more precision and purity
	Filtration through nanoelectropositive media can ensure improved filtration of pathogenic microbes, particularly those which are resistant to conventional depth filters
	Nanotechnology-enabled filters also ensure filtration of those viruses and bacteria which are too small to be filtered by conventional filters
	Providing clean and safe water at a lower cost

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Major challenges	What do the applications of nanotechnology offer?
Providing clean and safe water at a lower cost	Affordable desalination is the panacea to the water problem. The high cost of conventional desalination is mainly owing to the energy cost. By strategic use of ultrathin membranes, thanks to nanotechnology, high pressure pumps, energy recovery systems, pretreatment systems, back flushing, and other maintenance costs would be minimized substantially, some even eliminated. This would make desalination affordable even for the developing nations
Increasing the usability of unusable water through desalination, recycling	Nanofiltration membrane technology is widely used to remove dissolved salts from salty water, remove micropollutants, soften water, and treating waste water. Nanofilters can remove up to 99% of ammonia from contaminated waterways and sewage outflows. This allows the water to be recycled while the ammonia removed can be reused as fertilizer
Conserving water	Conserving water is as important as increasing the supply of usable water. Nanotech has immense potential in this area since this precision technology has strategic solutions to control waste of water flowing through canals through better linings and coatings, better drip and sprinkler systems, more efficient coatings to stop seepage in household and industrial water systems, and less requirement of back flush in filtration systems
Preserving the essential nutrients in water like calcium, etc.	Nanotech-based filters can precisely select the substances and hence retention of essential ones will be possible. Measuring and monitoring contaminants at the trace level, nanofilters can analytically and effectively measure and monitor contaminants like arsenic, mercury, and others even at the trace level, unlike the conventional ones which can measure only the concentrated high level contaminants
New possibilities	Nanoscience enables various strategic applications as under: Purification applications, ranging from high purity semiconductor and medical uses through home drinking water, remediation of both waste water and polluted ground water. Desalination applications, including both sea water and brackish water

2.2.3 Environment-Related Energy Sector

Major challenges	What do the applications of nanotechnology offer?
Cleaner conventional energy	Production of electricity from coal or natural gas can be made more efficient by strategic use nanotechnology in turbine plants
	In nuclear energy, nanotechnology can help improve the radiation resistance of the materials
Dependable supply of renewable energy at affordable cost. The two big complaints against solar and wind power are high cost and intermittent supply as large-scale storage not possible	Use of nanotechnology in chemical reactions could provide hydrogen for tomorrow's fuel-cell powered vehicles. Cells with nanocrystalline coatings of metal oxides enable production of hydrogen gas directly from sunlight. Nano-structured turbines ensure efficient production of wind energy at lower cost. Nano-based solar cell and panels contribute a lot for efficient generation and transmission of solar power
	The batteries currently available are not suitable for large-scale storage. Strategic applications of nanoscience will help in creating large banks of batteries to make storage on a large scale possible
	Nanotech would also enable creating new kind of nanotubes-based capacitors which make batteries usable for indefinite period
Safe and large-scale storage of hydrogen energy. Conventional technology stores hydrogen in high-pressure tanks which is highly unsafe	Nanotechnology offers safe and practical solutions like absorption onto high surface area solids and use of carbon nanotubes and nano-structured graphite fibers for combining with metal hydride compounds
Fuel cell usage has been limited due to material performance and high cost since it needs platinum which is scarcely available	Nanoscale material can replace platinum completely or partially with increased efficiency for specific applications. Carbon nanotubes could enable a substantial improvement in the performance of fuel cells, together with a heavy cost reduction of catalyst material
Developing efficient transmission devices	Nanoengineering could lead to smart devices like smart windows, energy-efficient LEDs and wireless controls, and also highly efficient conductors and superconductors that could eventually replace current transmission facilities
	Strategic use of nanostructures would make any device energy efficient
Developing energy efficient distribution networks	Nano-enabled capacitors will create entirely new networks for local electricity storage which could ensure much lower rates of energy wastage and improved performance

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Major challenges	What do the applications of nanotechnology offer?
Addressing the issues of soil, water, and air pollution through strategic applications of nanoscience	Pollution monitoring using nanosensors lowers energy needs due to lightweight strong materials. Products with molecular-level precision through the use of productive nanosystems could result in virtually no chemical waste. Nano-enabled products like nanowire-based paper can clean up oil and other organic pollutants. Nano-sized particles of iron are useful for cleaning up contaminants in groundwater, soil, and sediments
New possibilities through nanotechnology	Personal power-jackets that could use heat from the human body to recharge cell phones and other electronic devices. Microbial fuel cells where an organism performs electron transfer mechanism are being developed through use of nanotechnology. High-powered batteries that can be used in electric vehicles are being developed by strategic applications of nanoscience

2.2.4 The Solar Energy Sector

Major challenges	What do the applications of nanotechnology offer?
Conventional energy is too expensive	Nanotech devices have given us the possibility of producing cheap power and enough for every one
Conventional energy is too centralized	Nanosolar cells embedded in flexible plastics will be able to adjust to the shape and terrain of the rooftops and/or could be put into the building materials like tiles and siding. Thus, it will be possible to produce energy at every rooftop
Conventional energy is polluting	Nanoenergy is clean; cleaner than anything else possible
Solar energy again is too costly	Nanotechnology has added to the possibility of producing solar energy which is cheaper than that from the conventional sources
How will it be stored?	Nanotechnology-enabled super capacitors will help in local storage of energy
How to reduce energy waste: transmission losses?	Nanosuperconductors will replace current transmission facilities and they will have better performance on this front
The photovoltaic cells that make up most present-day solar panels are made up of crystalline silicon, which requires clean manufacturing free of dust and airborne microbes. Silicon is short in supply and expensive	With nanotechnology, tiny solar cells can be printed onto flexible, very thin light-retaining materials, by passing the cost of silicon production. Thin rolls of highly efficient light-collecting plastics spread across rooftops or built into building materials Nanocells made up of materials, several thousand times smaller than hair, will have more light-capturing capabilities. Each nanosolar cell will be an energy collector and spread with the plastic sheets, and will cover large surface areas than photovoltaic cells

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Major challenges	What do the applications of nanotechnology offer?
High manufacturing costs lead to high prices	Nano-enabled plastic solar cells can turn the sun's power into electrical energy, and they are many times more efficient than present solar cells
	Flexible sheets of tiny solar cells made by using nanoscience applications may be used to harness the sun's energy and will ultimately provide a cheaper, more efficient source of energy
	By integrating applications of nanoscience "solar farms" may be created which consist of the plastic material with solar cells which can be rolled across deserts to generate energy
What are the further possibilities?	Nanotubes, because of their structure, exhibit electrical and optical properties, which help in the absorption of solar energy and its conversion to electrical energy
	Nanoparticles like quantum dots with a polymer to make the plastic can detect energy in the infrared solar rays. This will strategically capture more solar energy
	Nanoscience also enables production of solar cell glass that will not only generate energy, but also act as windows in future houses and commercial buildings. While it captures solar energy to power the building, it also reduces overheating of the house thereby reducing the need for cooling
	Dye-sensitized nanosolar cells using photosensitive dye which do not require costly and large-scale production equipment

2.2.5 Medicine and the Healthcare Industry

Major challenges	What do the applications of nanotechnology offer?
A surgery causes wounds which take long time to heal. Cancer therapy is damaging to many other important parts. The trial and error method of drugs have side effects. Organ transplantation may result into crippling the entire immune system. Many health problems cannot be cured at all	The present practice to deliver a chemical in the body is to dump it into either the bloodstream or the stomach, and let it spread all through the body
	For some chemicals like insulin, it is acceptable. But for others, such as chemotherapy drugs and some antibiotics, it is best to keep them as local as possible
	Strategic nanotechniques can help the humanity: can put drug delivery devices right where they are needed
	Nanomedicines and nanotech machines have created the possibility of diagnosing, treating, and preventing disease with the use of smart drugs and equipments that target specific organs or cells
Reducing the side effects or damages to nontarget cells	Nanotechnology has the potential of engineering particles to be used for detecting and treating the diseases or injuries within the targeted cells, thereby minimizing the damage to healthy cells in the body

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Major challenges	What do the applications of nanotechnology offer?
Avoiding unnecessary damage to other cells while treating a particular cell	Nanomedicine holds good promise in this regard. This involves the use of manufactured nanorobots to make repairs at the level of specific cells
Avoiding infection during surgery or in wounds	Nanocrystalline silver is already being used as a antimicrobial agent in the treatment of wounds
Targeted diagnostics, treatment, and drug delivery	Very useful devices using nanotechnology and other nanoproducts are under development which include: • Qdots: which can identify the exact location of cells (e.g., cancer) in a body • Nanoparticles: that deliver drugs directly to cells to minimize damage to healthy cells • Nanoshells: for focusing the heat from infrared light to destroy cancer cells with minimal damage to surrounding healthy cells • Nanotubes: They are used to repair broken bones; to provide a structure for new bone material to grow • Cell repair machines: They will almost be of the size of bacteria and viruses. They will be able to travel through and enter the tissues like white blood cells and viruses. They will also be able to open and close the cell membranes with the care and precision of a surgeon • Similarly, selective destruction of diseased cell will also be possible by applications of nanoscience: identify them and destroy
Easy and cheap diagnostics	Portable diagnostic nanokits are being developed like the ones available for sugar and pregnancy test, no need to go to a lab or wait for hours for the report
Future applications in nanomedicine	In eliminating bacterial infections in a patient: it can be done within minutes through nanotechnology-enabled medicines, instead of treating with antibiotics over a period of few weeks • To perform surgery at the cellular level: this will help removing individual diseased cells and even repairing defective portions of individual cells • With drugs and surgery, the physicians presently cause the tissues to repair themselves. Whereas nano-enabled molecular machines will affect more direct repairs, thus bringing a total revolution in medical science • Substantial increase in the human lifespan: by strategically repairing cellular level conditions that cause the body to age by use of nanotechnology • The programmed nanomachines will treat even unknown diseases. They identify any foreign element and destroy it to ensure good state of health

2.2.6 *The Materials Industry*

Major challenges	What do the applications of nanotechnology offer?
They are heavier and bulky even if the weight is not a requirement of the product	We can make nanomaterials as precise and compact as required through strategic applications of nanoscience
There is a lot of waste and hence waste management is a big issue	Waste management will be easier not only because the materials will be nano, but also because the technology itself will bring out materials that solve the problem
There is lot of transmission loss in transmission of electricity Nanomaterials offer the best in that regard	One reason for this is that the materials used for transmission, for example copper, are not good conductors. Nanotech carbon fibers will have very good conductivity/semiconductivity
There is loss of fuel consumption in several applications like auto and aerospace	With carbon nanomaterials, the weight of these devices will be much lesser and hence fuel consumption will be reduced
Stain and corrosion in most materials	Nanomaterials offer the best in that regard

2.2.7 *Nanotechnology and Textiles*

- Materials that take away sweat and make the clothing free of body odor have been developed using nanotech
- Adding metal nanoparticles enables anti-odor functioning in the cloth
- The conventional stain-free coatings make the cloth stiff and fuzzy and are washed away over a period of time. Nanotech applications help making materials that develop chemical bond with the fibers and the cloth remains smooth and stain free
- Adding metal and semiconductor nanoparticles give the cloth glittering long-lasting colors and wrinkle-resistance besides high-end features like protection against UV rays and antimicrobial function can be available
- Nanofibres render strength and durability which delays the wear and tear substantially
- “Smart” nanomaterials could do some of the things living things do, such as heal breaks and wounds, or change color or shape for protection in response to what is going on around them
- Right now you can buy jackets with disc players and controls sewn in but they are quite bulky and messy. Nanotech would give a new dimension to this segment of wearable electronics with production of a new generation of garments with distributed sensors and electronic function. They will go far beyond just very small electronic devices or wearable, flexible computers
- Not only will these nanotech devices be embedded in textile substrates, but a nanoelectronic device or system could ultimately become the fabric itself
- Nanotech application would lead to textiles with biomonitoring commands that will heat or cool its wearer and change color as per the surrounding
- Nanotech-based smart clothes would remotely monitor home-bound patients capturing vital data and then beaming it wirelessly to a doctor, a hospital, a family member, or wherever it needs to go

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- E-textiles and smart nanotextile would allow leveraging an existing low-cost textile manufacturing infrastructure
- Textiles made by attaching nanolayers to natural fibers can control what passes through the layer. These layers can be customized for different chemicals such that hazardous gases and chemicals can be blocked while still allowing air and moisture to pass through
- Novel nanoscale fibers can be placed inside a garment or paper document to serve as a “fingerprint” that proves the product is genuine. The fibers can essentially serve as molecular bar codes
- Garments treated with metallic nanoparticles prevent colds and flu
- Electrostatically charged nanoparticles and nanosilver protect the wearer from smog and air pollution

2.2.8 Construction Industry

Major challenges	What do the applications of nanoscience offer?
Maintenance of glass structures	Antifogging and self-cleaning glasses, low maintenance windows
Rusting and scratch long lasting	Scratch-resistant floors using nanotechnology
Corrosion/rusting in structures	Super strong structural components made with nanotechnology
Low life of paints: fading, etc.	Longer-lasting house paint using nanotechnology
Numerous problems solved at one stroke by integrating nanoscience	Healthy and safe indoor environment using nanotechnology; self-cleaning skyscrapers using nanotechnology; antimicrobial steel surfaces using nanotechnology; better industrial building maintenance; less energy-consuming buildings using nanotechnology; long-lasting roads and bridges using nanotechnology; self-sterilizing kitchen counters using nanotechnology
	Numerous problems solved at one stroke by integrating nanoscience
	Humidity controlling materials using nanotechnology

2.2.9 Chemicals Industry

Major challenges	What do the applications of nanoscience offer?
Chemical vapors	Chemical vapor sensors: nanotechnology-enabled sensors can detect even small amounts of chemical vapors. Detecting elements like carbon nanotubes, zinc oxide nanowires, or palladium nanoparticles can be strategically used in nanotechnology-based sensors. This will help us monitoring the quality of air very easily

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Major challenges	What do the applications of nanotechnology offer?
How to detect low concentrations through strategic detection?	Since the size of the above nanodevices is small, even a few gas molecules are sufficient to change the electrical properties of the sensing elements. This allows strategic detection of even very low concentration of chemical vapors. These nanotech-enabled sensors can be installed at any establishment to check the level of chemical vapors
Management of hazardous substances	Nanotechnology-driven innovations will definitely have the potential of reducing risks relating to several hazardous substances and chemical processes
	Chemical substitution is a vast area opened by the applications of nanoscience. An important example is the substitution of antifouling nanocoatings, used in the ship industry
Major applications of nanoscience under development	Sensors which use: "zinc oxide nanowire detection elements" capable of detecting a variety of chemical vapors; "carbon nanotube detection elements" capable of detecting a variety of chemical vapors; "pallidium nanoparticle detection elements" to mainly detect hydrogen gas

2.2.10 Space Industry

Employing materials made from carbon nanotubes to reduce the weight of spaceships like the one shown below while retaining or even increasing the structural strength
Using carbon nanotubes to make the cable needed for the space elevator, a system which could significantly reduce the cost of sending material into orbit
Including layers of bio-nanorobots in spacesuits. The outer layer of bio-nanorobots would respond to damages to the spacesuit, for example, to seal up punctures. An inner layer of bio-nanorobots could respond if the astronaut was in trouble, for example, by providing drugs in a medical emergency
Deploying a network of nanosensors to search large areas of planets such as Mars for traces of water or other chemicals

2.2.11 Defense Industry

Rapid and inexpensive manufacture of great quantities of stronger and more precise weapons guided by increased computational power
Virtual reality systems based on nanostructure electronics that enable more affordable, effective training
Enhanced automation and robotics to offset reductions in military manpower, reduce risks to troops, and improve vehicle performance
Higher performance military platforms that provide diminished failure rates and lower life-cycle costs
Improvements in chemical/biological/nuclear sensing and casualty care

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Nuclear nonproliferation monitoring and management systems combined nanomechanical and micromechanical devices for control of nuclear defense systems
Bionanobots might be designed that when ingested from the air by humans, they could assay DNA codes and self-destruct in an appropriate place, probably the brain, in those persons whose codes had been programmed
Nanobots could be designed to attack certain kinds of metals, lubricants, or rubber, destroying conventional weaponry by literally consuming it
New realms of clothing would be possible, such as smooth, strong fabrics; sensory-enhanced garments of fibers mixed with nanochip, and able to absorb or reject chemical agents or toxins

2.2.12 Other Applications

Nanotechnology in electronics:
Laptop computer screen: thickness and weight of a piece of paper
Computer chips: which can store the information equivalent to all present computers of the world
Nanotechnology in automobile, electrical, and aerospace:
Carbon materials like fullerenes, metal oxides, and nanotubes and fibers display very high mechanical and electrothermal conduction abilities. At the same time, their weight is far less and strength is far greater
Nanotech applications in production of carbon fiber, and the machine parts with wear-resistant, erosion-resistant, and corrosion-resistant
Important nanotech materials and their applications:
Metal oxides such as Alumina, Zirconia, Ceria, Zinc oxide-Car catalysts, antibacterial functions, structural ceramics, sunscreens, fuel cells, transparent UV absorbers
Carbon—Thermal and Electrical conductors
Alumino silicate (imogolite)—Ceramics filter, Catalyst support, and humidity controlling building materials
Calcium phosphates (hydroxyapatite)—Implants such as eyes, knees, and hips

2.3 The US Issues of Diffusion and Problems That Are Faced by the Developing Countries

2.3.1 Nanotechnology and the US

A relatively recent report prepared by the U.S. Department of Commerce Technology administration (2007) helps us place the issues that are related to the development of this controversial, complex yet simple technology and its future. As we can see, a sophisticated economy that has very different issues to tackle with the advancement of a critical technology has to make its own policy decisions and apply its own strategies to tackle these problems.

Given below are the issues that the report points out as problems related to this industry in the US.

- Research and Development: Infrastructure availability is lacking, yet crucial to assist businesses, especially small companies that cannot afford the cost of nanotechnology instrumentation, equipment, and facilities. Nanotechnology virtually demands university and industry cooperation due to basic science innovations, expensive laboratories, and need for highly trained workers.
- Investment: The necessary and substantial Investment Capital, cash, is lacking early in business ventures for highly educated personnel and advanced R&D systems, high processing costs for nanoproducts, perception of long lead time for nanoproducts, and lack of process scalability.
- Intellectual Property (IP): IP is vital for new ventures needing core technology licenses and help from investors. There is need to enhance IP protection to attract investors besides enacting stronger R&D tax credit and providing tax incentives for U.S.-based development ventures.
- Economic Development and Commercialization: Efforts by regional, state, and local initiatives, mainly by governments and institutions, are not yet causing significant increases in new nanotechnology private sector jobs.
- Workforce Development and Education: Companies seek to locate manufacturing in communities that have trained workforces. The US national trend is leading away from traditional careers in technology at community colleges, undergraduate and graduate universities. Unfortunately, most of academia and the research community do not facilitate a nanotechnology-oriented type of multidisciplinary research.
- Occupational Health: Human exposure to nanomaterials in the workplace and indoor and outdoor environments show a need for early monitoring of workers subject to high nanotech exposures and toxicity concerns.
- Public Policy and Health: The public perception toward the federal government from public knowledge about, and attitude toward, the Food and Drug Administration (FDA), Environmental Protection Agency (EPA), and U.S. Department of Agriculture (USDA) is good to excellent but ambiguous toward business, according to a survey.
- Government Budget: Government assistance is vital to help finance nanotechnology infrastructure that requires higher investments and costs for multidisciplinary ventures, and risk research of the environment and human health. Government should offer tax incentives to encourage safer environment by business, purchase desirable nanotechnology products and services, and amend regulations to favor certain conduct and outcomes.
- Nanotechnology Standards: There is urgent need to develop standards for each aspect of the new nanotechnologies: research, production, products, and waste disposal.
- Global: Global concern is growing since about 75% of known nanotechnology R&D investment worldwide is done by foreign nations, and even more unknown amounts by private industry, thus making environment, health, and safety all

international issues. Foreign competition might surge if they can operate with little regard for these issues.

- Instrumentation and Metrology: Instrumentation and Metrology standards are lacking although vital to developing the basic terminology and comprehensive nomenclature of nanomaterials and products. Metrology, the science of measurement, underpins all other nanoscience and nanotechnologies not only because it allows the characterization of materials in terms of dimensions but also in terms of attributes such as electrical properties and mass.
- Nanobiotechnology: The science and engineering of nanobiosystems is one of the most challenging and fastest growth sectors of nanotechnology. Although applications of nanotechnologies in medicine seem especially promising, the unknown dangers and potential liabilities could become daunting.
- Energy: Nanotechnology and nanoscience advances are leading to improved energy resources that might be packaged in every conceivable way and location. The long-term impact of such packages and eventual disposal in the environment are unknown.
- Society: Nanotechnology acceptance by the public is subject to the extent of hyperbole in publications, classes of people with power and wealth compared to others who are helpless, and types of issues affecting public health and safety. The public impression generally is that risks from nanotechnology would outweigh the benefits derived.
- Risk Management: An integrated risk research framework by government is needed to manage nanotechnology environmental, health and safety issues by coordinating many agencies.
- Environment: There is immediate need to focus efforts on the types of nanoparticles already being used by industry, as these pose the most immediate exposure threat to humans and the environment.
- Nanotechnology Materials: Developing and validating methods to evaluate the toxicity of engineered nanomaterials is required, especially in the next 5–15 years. Much of nanoscience and many nanotechnologies are concerned with producing new or enhanced materials.
- Conflict of Interest: An issue universities should anticipate and help to manage is their nanotechnology innovation transfer terms and related conflicts of interests at all levels involving professors, industry, and government.
- Nanotechnology Devices: Nanotechnology applications as devices may include active nanostructures (anticipated rapid growth markets from 2005 to 2010) that change their state during use, responding in predictable ways to the environment around them. However, there is concern that the public would become wary and might refuse acceptance of such devices.
- Nanotechnology Manufacturing: Systems of nanosystems (anticipated rapid growth markets from 2010 to 2015) are assemblies of nanotools working together to achieve a final goal and could lead to large volume nanomanufacturing processes. A key challenge is to get the main nanocomponents working together as a network, possibly automatically exchanging information to make things from molecular size "bottom–up." Over time, some traditional industries currently

making things from existing materials “top–down” would be displaced, along with their workers.

- Related Services: Successful commercial exploitation of nanotechnology products requires unprecedented levels of collaboration (both vertical and horizontal) across many different realms in order to adequately address the inherent complexities associated with the lifecycles of such products. At present, there are no sophisticated networks of collaboration.
- Outer Space: Nearly every space program worldwide has found remarkable and successful roles for Micro- and Nanotechnologies (MNTs).

These have been developed in response to the lighter-weight, smaller-size, less power-dissipation, lower-cost mantra chanted by those involved with commercial outer-space, aerospace, and military applications. Although these highly specialized industrial sectors are not directly relevant to general business and consumers, the spin-off technology could enrich global markets.

As one can easily ascertain, for the US to benefit from all the solutions that nanotechnology can offer does not come unchallenged. The main issues are naturally the displacement of workers and loss of jobs, the unknown consequences to the environment and the human health if nanotechnology research indeed gets to be diffused across all industries. What we conclude is that the implications of this science need to be studied carefully and should not be hindered by personal worries but rather realistic assessments should place and determine just how far a country with all the necessary infrastructure can go.

2.3.2 Nanotechnology and Developing Countries

In Table 2.1 we can view the countries classified as developing, transitional, and developed that are involved in the nanotechnology activities.

There is an obvious correlation between the income levels, low levels of R&D and health-care spending by governments, and efforts to invest in nanotechnology. Of course as Mac Lurcan (2005) adds the weak infrastructure, low skill levels, and bad policies along with the costs that are required to be incurred, weak intellectual property rights, inadequate education at the academic and the public level, the brain drain problem along with the trade barriers and political context are likely to create barriers (though not unique to) for the advancement of the nanotechnology industry. Advancement involves the diffusion of the technology across the entire economy.

The cost issue: It would help the reader have some perspective if we provide examples as to how costly it is to set up a nanotechnology facility. In Costa Rica, for example, a new nanotechnology facility, with a clean room, reportedly have costed about $50,000 and to equip it will cost extra several hundred thousand dollars.

Rao claims an Atomic Force Microscope, a fundamental tool for characterization at the nanoscale, costs approximately $1.5 million, the ETC Group puts this figure at $175,000. Despite these figures, however, as Salvarezza puts it, even the developing

Table 2.1 Global distribution of nanotechnology activity by country and classification

Least developed	Developing	Transitional	Developed
National activity or funding			
	Argentina; Armenia; Brazil; Chile; China; Cost Rica; Egypt; Georgia; India; Iran; Mexico; Malaysia; Philippines; Serbia & Montenegro; South Africa; Thailand; Turkey; Uruguay; Vietnam	Belarus; Bulgaria; Cyprus; Czech Republic; Estonia; Hong Kong; Hungary; Israel; Latvia; Lithuania; Poland; Romania; Russian Federation; Singapore; Slovak Republic; Slovenia; South Korea; Ukraine	Australia; Austria; Belgium; Canada; Denmark; Finland; France; Germany; Greece; Iceland; Ireland; Italy; Japan; Luxembourg; Netherlands; New Zealand; Norway; Portugal; Puerto Rico; Spain; Sweden; Switzerland; Taiwan; United Kingdom; United States of America
Individual or group research			
Bangladesh	Botswana; Columbia; Croatia; Cuba; Indonesia; Jordan; Kazakhstan; Moldova; Pakistan; Uzbekistan; Venezuela	Macau (China); Malta; United Arab Emirates	Liechtenstein
Country of interest			
Afghanistan; Senegal; Tanzania	Albania; Bosnia and Herzegovina; Ecuador; Ghana; Kenya; Lebanon; Macedonia; Sri Lanka; Swaziland; Zimbabwe	Brunei Darussalam	

Source: Journal of Nanotechnology Online or less-developed countries can do research on nanotechnology as this research can be done by using relatively cheap equipments such as computer and scanning probe microscopes. In addition, Welland refutes the idea that drug research has to be capital intensive. The author argues that pocket-sized, drug factories "could theoretically end the control of large companies over manufacturing."

These ideas are not left unchallenged as, for example, Waga argues that as scientists work with matter on a smaller scale approaching the nanoscale, more sophisticated and expensive equipment is required. Is the cost issue a fundamental problem or not and how it should be handled is controversial. What we have in our hands is an emerging technology with variety of applications—some more sophisticated than others (some R&D activity involves less sophisticated powders and some complex quantum computers). One has to understand that an easy access to affordable research in niche application areas could be the right strategy for less-privileged countries.

Partnerships and access to information: Partnerships between countries are crucial for successful developing country engagement in nanotechnology. The National Science Foundation in the US suggests that countries can gain from precommercialization stages of R&D in nanotechnology and argues that research groups in different countries can provide complementary expertise to solve common problems. In 2002, the NSF had already developed partnerships with India and the Asia Economic Cooperation group and, since then, has been integral in the development of national nanotechnology initiatives in Vietnam and Costa Rica.

Likewise, the European Commission has also engaged in widespread participation and within the borders of the Sixth Framework Programme European Commission has been funding the nanotechnology projects from developing countries. For example, European Commission has simultaneously engaged in partnerships in nanotechnology with Argentine, India, Chile, China, Russia, and Africa.

On the other hand, The Asia Nano Forum involves 13 countries including China, India, Hong Kong, Singapore, Thailand, South Korea, Indonesia, Malaysia, and Vietnam. However, apart from South Africa and India, there seems to be no evidence that suggests partnerships with the countries in the bottom third of the Human Development Index. However, in countries like Pakistan, Bangladesh, and Botswana, the nanotechnology research is being initiated and Kenya, Senegal, Swaziland, Ghana, Tanzania, and Afghanistan expressed interest for nanotechnology partnerships. At this point, we have to caution the reader that the low development levels obviously are not conducive to such research partnerships and expectations of achievement from less-developed countries are relatively low.

Research and development efforts, theoretical vs. applied: There is a long gap between the results obtained in a laboratory and its commercial application as a market product. One such reason is the gap between a researcher and applied scientists. The scientists especially in developing countries, who have technology where nanomaterials are involved or used, are usually interested in publishing papers rather than scaling it up for its commercial application. This also leads to a time gap in scaling up the technology because papers are published on the bench scale data, which faces many difficulties in scaling-up procedure. In addition in developing countries, there is a lack of a coherent policy on tech transfer from universities to commercial units and a lack of institutional structure.

Weak Intellectual Property Rights—getting a patent is time-consuming which delays the process; in addition the patent office personnel do not have enough qualified staff to assess nanotechnology products. It is of course also the case that in many developing countries property rights are rather weak.

Low marketing skills—Developing country standards of regulations in terms of environmental and health issues are often rather weak. This of course is likely to hamper exports and domestic demand.

Lax standards—Lack of standards in the field of nanotechnology hinders the advancement. Lax regulations may help these countries to offer products at a lower price but on the other hand it lowers the credibility in the international market. Although these countries might have the required regulations to curb unethical practices, their governments do not have proper implementation skills.

We have mentioned issues related to the diffusion of nanotechnology across different industries in the US and in general in developing countries. Challenges are different for each. For developing countries, the road to such diffusion might not prove as formidable as there are many niche areas these countries can concentrate on which would not require as much expensive infrastructure. The issues of weak property rights, low level of environmental and human life concerns are issues and regulations need to be implemented properly. A major step for any developing country is to have centers of applied nanotechnology research that would not require immense funding and that can help these countries to export their products in the international markets. Much is unknown, much remains to be seen.

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http://www.springer.com/978-1-4614-1544-2

Making It to the Forefront
Nanotechnology—A Developing Country Perspective
Aydogan-Duda, N. (Ed.)
2012, XVIII, 166 p., Hardcover
ISBN: 978-1-4614-1544-2