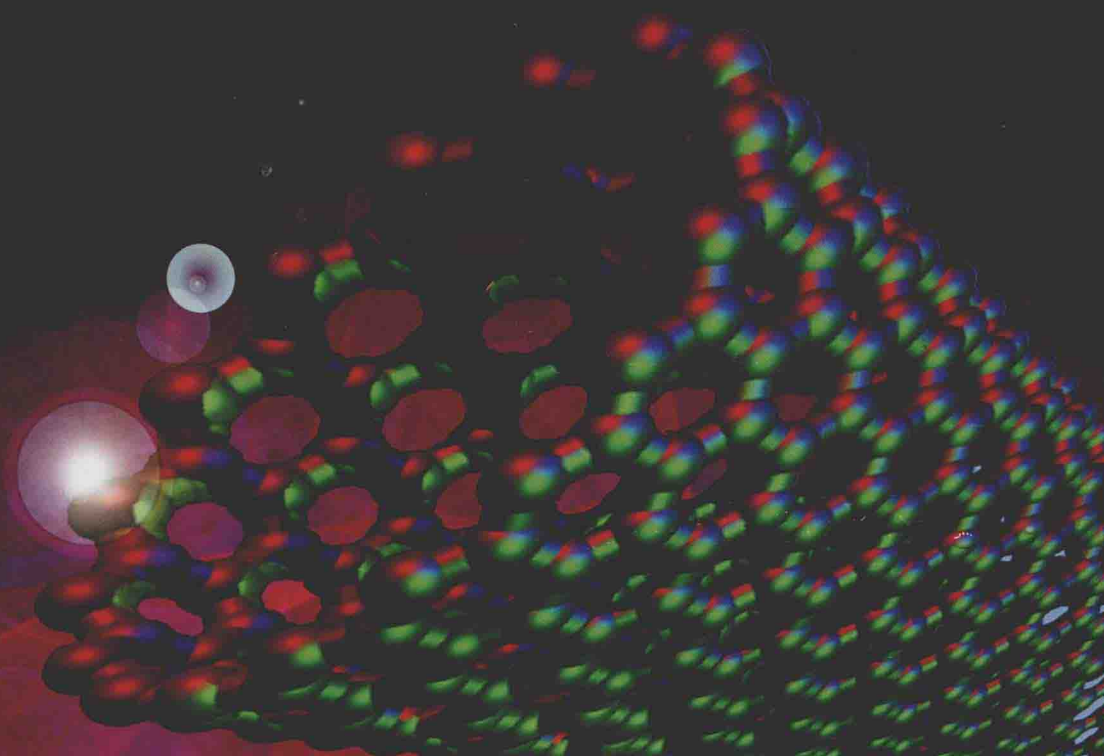
Nanotechnology Science and Technology

Nanotechnology

Recent Trends, Emerging Issues and Future Directions



Nazrul Islam
Editor

NOVA

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RECENT TRENDS, EMERGING ISSUES AND FUTURE DIRECTIONS

NAZRUL ISLAM
EDITOR

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New York

PREFACE

Schumpeter's 'long-wave theory' explains the technological revolutions underlying the 'Kondratieff' cycles, and comprises his work on business cycles, with successive industrial revolutions or long waves of technical change. For example, cotton was a key factor in textile innovations in the first Kondratieff cycle; coal and iron for the industries associated with steam power and railways in the second Kondratieff; steel for the industries based on electric power, chemicals manufacture in the third Kondratieff; energy or oil for industries such as consumer electronics, synthetic materials and pharmaceuticals in the fourth Kondratieff; and chips or integrated circuits for innovations based on information and communication technology (ICTs) in the fifth Kondratieff. Neo-Schumpeterian theory (built upon Schumpeter's theories of long cycles in economic development) emphasizes the long wave relationship between economic and technological development, arguing that such fundamental technological changes bring discontinuity in economic development, but also act as important engines of economic growth. Experts argue that nanotechnology innovation is the harbinger of the sixth Kondratieff, as it is likely to bring revolutions in science and technology arenas.

Respecting the above argument, I would like to propose that nanotechnology conforms to an 'evolutionary' field of micro-technology, rather than being 'revolutionary'[1]. Drawing from modern evolutionary economics, the concept of 'evolution' is used in the sense of a pattern, or principles of change. The current conceptualization of evolutionary change involves explicit principles of change, specifically the generation of novelty, selection among diversity, as well as the retention and transmission of information. Technology evolution thus has a meaning similar to that in biology, rather than simply meaning path dependency or incremental change. Stimulated by biological theories, evolutionary ideas (comprised of variety and natural selection) were introduced assuming that technical change evolves through similar concepts of natural selection as with biological species. Genes are the basic unit of evolution, and improve the reproductive capacities through the dynamics of variation and natural selection. Studies on evolutionary theory found an analogy between the evolution of behavioral routines and the evolution of genes in biological systems, and then suggested that technologies had natural trajectories of their own.

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[1] For thousands of years we characteristically used a scale of something like the meter, for the last 50-60 years it has been the millimeter and for the last 30-40 years, we have the micron scale and micro-technology. Nanotechnology is an evolution from the micro to the nano-scale.

Technology is seen as an important determinant for the survival and growth of companies, regions and nations and is related to new theories of economic development, technological change and industrial innovation. In order to reach technology-based economic growth, it is not only necessary to invest capital, intellect and time in technology-related research and development (R&D); but also to execute processes related to technology development trends, diffusion patterns, and the adoption and implementation of technology-based innovations. Technology-based innovations fuel the knowledge-based economy, as it creates new industries, makes existing ones globally competitive, and drives future economic growth. Nanotechnology has been regarded as a science and technology-based innovation, an exploration of molecular or atomic engineering that has the potential to produce sweeping changes to almost all aspects of human society beyond the scope of conventional technologies. For example, nanotechnology encompasses distinct areas such as precision engineering as well as electronics; electrochemical systems (lab-on-a-chip devices), as well as mainstream biomedical applications in areas as diverse as gene therapy, drug delivery and novel drug discovery techniques. Therefore, in nanotechnology there can be both a mechanistic version (*more materials science and microelectronics inspired*), and a bio-mimetic version (*more biotechnology inspired*).

Nanotechnology has gained increasing public as well as institutional attention worldwide. This technology has contributed to remarkable advances in the field of science and technology in the past two decades, which have led to significant prospective applications in various technological domains including advanced materials, biotechnology and pharmacy, electronics, scientific tools and techniques, and industrial manufacturing processes. Nanotechnology is today considered as being a general-purpose technology, and will become a common technology for all sectors or industries because of its ability to create super-functional properties of materials at the nano-scale. On this scale, the classical laws of science do not readily apply and therefore new properties and functionalities arise because of ultra-small size and quantum-mechanical behavior of the elements of the material. As the nano-materials industry develops and matures, it will increasingly become more affordable and cost competitive with conventional materials, while offering a superior or novel performance. Even today, the volume and pricing of nano-materials is already in the range where a number of commercial applications appear economically compelling. Nano-materials play a significant role in combating pollution and environmental hazards, by enabling advanced water purification and clean energy technologies, and they have a profound impact in the medicine sector. This ultra-small technology will drive a new technology-driven global economy, with revolutionary advances in almost all industry sectors through high utility and demands. However, owing to the expected impacts of nanotechnology, the abilities of nations to adopt and drive penetration in their economies will affect their economic viabilities in the long-run.

The huge potential of nanotechnology has encouraged a dramatic rise in research and development (R&D) in almost all developed countries, and many developing countries have begun to invest in nanotechnology areas. Hardly any other technology has attracted so much public and private funding globally as fast, and generated as much hype and science-fiction-like speculations about its technical, commercial and social potential. Nanotechnology is a priority field now worldwide, including the US, in several countries in Europe (such as Germany, France, UK and Italy) and in Asia (in countries such as Japan, China, South Korea, Taiwan and Singapore); and increased funding has been made available over the periods in the relevant research. Many scholars expect nanotechnology to be as significant as the transistor and the Internet in terms of societal impacts. Substantial efficiency, high utility and demand for nanotechnology products will drive the nano-revolution which will help advance genetics, information technology, biotechnology and robotics. Yet, despite these pervasive impacts of these innovations on daily lives and businesses, the study focuses on the technological development and the diffusion of trends and challenges have been rather limited.

The book is written to assess the state of nanotechnology development trends and to identify emerging and mature technologies and their relevant application domains in general. My approach in this project is guided firstly by a general outline of nanotechnology and its potential impacts, followed by a quantitative conception of the production of nano-technological knowledge at the actor and activity level; subsequently I consider examining the challenges and identifying emerging issues, and finally I suggest the key issues to be focused on in the future with personal directions, finishing with managerial and policy recommendations. The study provides an overview of the developments made in nanotechnology to date, the ongoing trends and the future prospects, together with the supply chain practices and environmental risk challenges involved.

It is important to explore carefully the relevant steps and approaches that lead the following empirical research. In order to build this, it is necessary to understand the nature (such as emerging characteristics, historical developments etc.) of the technology area in question. People who are not familiar with the scientific and technological aspects of the technology or area of study may find it difficult to follow the order of the steps of the analysis. First, I discuss the recent technology development trends of nanotechnology, with a particular attention paid upon the subcategories of this field, illustrating the different strands of the field, and thus helping the reader to understand what the field is about. I then concentrate on identifying its emerging issues and infrastructures, and forecast future prospects and directions. However, for over a decade, an international policy debate has been taking place regarding the appropriate mechanisms for the governance and regulation of advances in nanotechnology. Companies are faced with the challenge of harnessing the enormous potential of nanotechnologies, while also being attuned to potential environmental, health and safety issues, and social acceptability. The lack of investigations in these areas still poses a serious barrier to the commercialization of nanotechnology-based products. The formation of nanotechnology regulation, which is currently under intensive investigation, is highly challenging for the regulatory and scientific communities - as it incorporates several new aspects of technology development, regulation and monitoring. Based on the increased awareness and extensive on-going efforts, it is expected that the coming years will witness many nanotechnology-based products in the market which will have a potential technology impact.

This book explains how nano-science, technology and technological progress are central to economic and social well-being, and why the creation and diffusion of nano-products with secure and safe development, along with an efficient supply chain are critical drivers of adopting this technology. Some aspects focus on the present scenario and future scope of nanotechnology applications in spin-device technology, next generation nano-composite ultrafiltration membranes for water purification, nanoemulsions for drug delivery; pharmaceutical and biomedical applications of grapheme, and the conceptualization and development of nanomedicines nano-enabled drug delivery systems, for example the polymeric nano-carrier dendrimers to deliver anticancer chemotherapeutic drugs for cancer therapy. There is evidence of the growing field of nanomaterials formed by green nanotechnology for bioapplications to minimize the potential human health and environmental risks associated with the manufacture and the use of nanotechnology products in general. It is urgent to apply nanotechnology to solve legacy environmental problems, and to encourage the replacement of existing products with new nano-products that are more environmentally friendly throughout their life cycles. With more than 1000 nanotechnology-based product already in the market, the exposure to nanoparticles is expected to increase day-by-day, but there have been no clear-cut guidelines for the toxicity evaluation of nanoparticles. Along with toxicity evaluation, the use of a predictive toxicological paradigm has also been advocated.

The authors discuss the understanding of the key factors that seem to drive and facilitate the convergence of nanotechnology with life sciences, by identifying gaps in the business and innovation models and to define the corrective actions that could facilitate improved product adoption among the life sciences and medical community. Mapping the role and dynamics of stakeholder interactions and knowledge flows, that define the elements of the nanotechnology innovation ecosystems, has been established through a comparative evaluation of the country specific ecosystems. Others confer to the industry's response to the pressures of the responsible development of nanotechnology, for making every reasonable effort to anticipate and mitigate the adverse implications or unintended consequences. It is also important to note that there is need for the developing countries to engage in nanotechnology development early to avoid the dependency syndrome, since further delay may result in the technology putting down its roots in the mainstream hegemonic socioeconomic structure characterised by global inequality. Developing countries should prioritise domestic innovation and technological advancement in order to contextualise the technology to the social and economic imperatives of the poor in sub-Saharan Africa. On this basis, it is recommended that the developing countries should not mimic the research and development programmes of the developed countries, but instead they should align them in accordance with the needs of poor. With limited financial resources to spearhead the development of the technology, public and private partnership should be encouraged. The end users of nanotechnology, particularly the poor and developing countries, should be given opportunities to participate in the development of the technology, as the social factors are crucial in the adoption of nanotechnology. This can be achieved through stakeholder participation, in which researchers, scientists and the community work in collaboration in coming out with products that suit the needs of the end users.

One major goal of this book is to highlight the multifaceted issues surrounding nanotechnology on the basis of case studies, academic and theoretical articles, technology trransfer, innovation, economics, management and policy. More than fifty experts spread in about fifteen countries with their respective understanding, perspectives, and resources provide a very broad audience to accomplish the project with. This book will be a useful reference for academics, practitioners, policy makers, and professionals in the field of science, technology, engineering, innovation, management and economics.

31 December 2013
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ABOUT THE EDITOR

Dr. Nazrul Islam is a Lecturer (Assistant Professor) in Innovation and Operations Management at Aberystwyth University School of Management and Business, UK. He has previously been appointed and taught in Cardiff University, Middlesex University, Tokyo Institute of Technology, North South University and University of Dhaka. He received the D.Eng. degree in innovation focusing on nanotechnology innovation management. Dr. Islam teaches technology and innovation management, operations and supply chain management. His areas of research interest include the management of emerging and disruptive technology innovations, nanotechnology systems of innovation, technology forecasting and roadmapping, assessment of technology readiness. Dr. Islam serves as a peer-reviewer to the UK research council (EPSRC) and for many international journals including editorial board membership. He has authored over 30 refereed journals papers including several books on the topic. Dr. Islam edited *Disruptive Technologies, Innovation and Global Redesign: Emerging Implications* published by IGI Global, PA, USA. He is also an author of a book on nanotechnology innovation system. His research works have been published in *Technovation, Technological Forecasting and Social Change, Science and Public Policy, and IEEE Transaction on Engineering Management.* Dr. Islam's publications have received academic awards including the '*Pratt & Whitney Canada Best Paper Award*' in R&D Management Conference, Ottawa, Canada. In recognition of his academic excellence, has won the '*Channel S Award 2010*' from London in the category of Achievement in Education, Research and Teaching in the UK. Dr. Islam has frequently delivered keynote speech, given invited lectures, and presented papers in international conferences worldwide. He is a professional fellow of the Higher Education Academy, U.K., an associate member of Institute of Nanotechnology, a member of American Nano Society, a member of International Association of Management of Technology (IAMOT) and a member of International Society for Professional Innovation Management (ISPIM).

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I also express my appreciation to the nanotechnology experts from academia and industry and the policy makers who have provided the necessary information through face-to-face interviews. Many contributions in this book have used data drawn from many of the sources; Thomson Reuters, ISI Web of Science, European Union, National Science Foundation, OECD, nanotechnology consortium, professional websites, among others. To all these organizations I gratefully acknowledge them for allowing the use of the required data. Having authored a book and co-edited a volume of earlier works that have shaped my interest in this project, it comes natural to thank my advisors and colleagues that are instrumental in inspiring me to complete this work. Through conferences, seminars, and workshops, I have picked up on vital ideas on the role of nanotechnology and its impacts in our modern economy and how the technology trends and progress could be sustained. I also appreciate all the contributors, whose works could not be included in this book due to editorial constraints.

Thanks to my parents for their blessings and for providing inspirations to reach for goals and achievement. My family has provided me encouragement with patience and support throughout challenging times. Finally, I dedicate this book to my parents, my wife and my two children Asif and Nahin, I thank you all for your continuous support and love, throughout this project and beyond.

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CONTENTS

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Chapter 1

NANOTECHNOLOGY: TECHNOLOGY TRENDS, EMERGING CHALLENGES AND IMPLICATIONS

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ABSTRACT

The purpose of this chapter is to present the subject matter and thereby explore the recent technology development trends, identify emerging issues and challenges that need to be investigated more generally and thoroughly, and to suggest key issues to be focused on for future agenda. Since nanotechnology is in its early stage of development, various factors and attributes can influence its emergence. The wide range of studies in this field may increase the rate of technology diffusion and shorten the pre-commercialized era, and so help it to move on to its highly commercialized era. However, the outcomes of current nanotechnology innovation systems, with their possible positive and negative effects on the environment and on existing industries, are uncertain. The challenges facing industry in the development of nanotechnology are substantial, given some areas of uncertainty (e.g., technical, commercial and social) which have been suggested in this study will affect the successful commercialization of nanotechnology. For the future development of nanotechnology, significant attention needs to be paid to facilitating the dissemination and absorption of nanotechnology knowledge, education infrastructure and research environments at institutional levels, massive investments in human resources and skills development, the efficient supply chain practices, stakeholder engagement and expanded public acceptability, effective procedures to evaluate nano-product's security and safety - along with the environmental and health issues in this industry being given a paramount importance in the decades to come.

Keywords: Nanotechnology, Technology Trends, Challenges, Future Agenda

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INTRODUCTION

Nanotechnology, with its ability to manipulate material properties and fabricate nanostructures, has become a very active and vital area of science and technological research; which is rapidly developing, spreading and touching across the whole spectrum of science and engineering disciplines, and is gaining increasing public as well as institutional attention worldwide. This technology has contributed to remarkable advances in the field of science and technology in the past two decades, which have led to significant prospective applications in various technological domains; including advanced materials, biotechnology and pharmacy, electronics, scientific tools and techniques, and industrial manufacturing processes. Nanotechnology has opened an era of the integration of fundamental scientific research and engineering at the atomic and molecular levels, emphasizing the nano size range of the structures and the ability to work at that scale, and the exploitation of properties and functions specific to the nano-scale, compared with macro or micro scales. The great physicist Richard Feynman's historic talk at the annual meeting of the American Physical Society at the California Institute of Technology in 1959, 'There's Plenty of Room at the Bottom - *An Invitation to Enter a New Field of Physics*', is widely considered to be the foreshadowing of nanotechnology - in that he suggested that the frontiers of knowledge and technology at which people should be aiming could be found not only in physics, but also in nano-sized fields (Feynman 1959). This famous talk clearly suggests that nanotech research is not confined to specific disciplines, but rather that it opens a door for multiple disciplines in science & engineering at the nano-scale or in nano dimensions.

The emergence of nanotechnology was enabled by the development of specialist instruments, which in turn facilitated the observation and manipulation of nanostructures at the atomic or molecular level. In the early 1980s, the inventions of the scanning tunneling microscope (STM) and a computer imaging system with atomic resolution provided the real breakthroughs. The most significant change has been brought about in nanotech by the discovery of this nano-tool, which enables the examination and observation of nanostructures or the building blocks of nanomaterials, and the manipulation of materials at the molecular and atomic levels. Since then, developments in nanotech have continued with significant discoveries of new nanomaterials such as 'fullerenes'[1] by Robert Curl, Sir Harold Kroto and Richard Smalley, and 'carbon nanotubes'[2] by Sumio Iijima; both of which offer a foundation for creating nanoproducts with enhanced performance parameters. Scientists and engineers have made significant developments in the improvement of methods of materials synthesis in the nano-scale. At present, the processes of production, synthesis, characterization, modification and functionalization of materials have been well established. The researchers' enthusiasm for nanotechnology advances was contagious. In the January 2000, President Clinton's administration gathered its various nanotechnology projects under the umbrella of

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[1] *Fullerenes,* called carbon 60, are a new class of carbon material which are spherical molecules about 1 nm in diameter, consisting of a stable cluster of 60 carbon atoms, a polygon with 60 vertices and 32 faces, 12 of which are pentagonal and 20 hexagonal, rather like the configuration of a football.

[2] *Carbon nanotubes (CNTs)* are extended tubes of rolled grapheme sheets, and can be single-walled or multi-walled types. CNTs have assumed an important role in the context of nanomaterials because of their novel chemical, physical and electrical properties. They are mechanically very strong, being as stiff as diamond, flexible about their axis and can conduct electricity extremely well. All of these remarkable properties give CNTs a range of potential applications; for example, secondary battery, field emission displays, hydrogen storage materials, capacitors, semiconductor devices, conductive coating materials, and sensors etc.