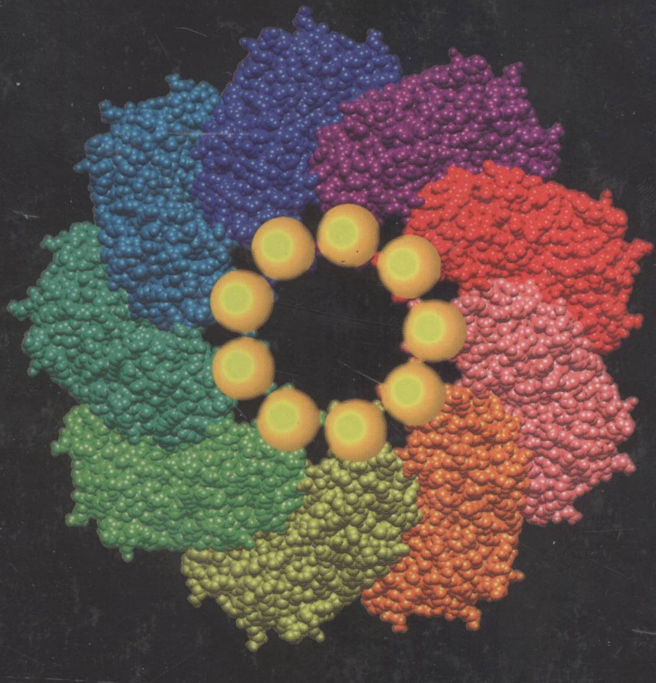
Nanotechnology: Societal Implications II

Individual Perspectives

Edited by
Mihail C. Roco and William Sims Bainbridge



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NANOTECHNOLOGY: SOCIETAL IMPLICATIONS II

About the cover

Protein-templated assembly image, courtesy of Andrew McMillan, NASA Ames Research Center (ARC). The computer-generated central image models heat shock proteins that have self-assembled into a double ring structure, 17 nanometers in diameter, called a chaperonin. The researchers can tailor both the chemical functionality of the chaperonin—in this case, the proteins have been genetically modified to bind to nanoscale gold particles—and its structural features. They can coax groups of chaperonins into a variety of 1-, 2-, or 3-dimensional structures, which serve as templates for creating ordered nanoparticle arrays. NASA researchers are exploring the use of protein-templated arrays as sensors and electronic devices.

This is Volume II of a two-volume set resulting from a workshop held under the auspices of the U.S. National Science Foundation and the Nanoscale Science, Engineering, and Technology (NSET) Subcommittee of the U.S. National Science and Technology Council on Dec. 3-5, 2003. The primary purpose of the workshop was to examine trends and opportunities in nanoscience and nanotechnology toward maximizing benefit to humanity, and also potential risks in nanotechnology development. Volume II contains essays contributed by the workshop participants. The companion Volume I is a summary of the findings of and discussions at the workshop.

Table of Contents

INTRODUCTION

This volume contains the 48 essays contributed to the most significant single effort to chart the societal implications of nanoscience and nanotechnology. The authors include natural scientists, social and behavioral scientists, engineers, philosophers, and legal experts. They work in industry, universities, government, and private practice. All have thought deeply about the profound implications of the newest realm of science and technology.

The first major examination of the human future of nanotechnology was a workshop held in September 2000 at the National Science Foundation that resulted in an influential book-length report [1]. More than three years later, in December 2003, knowledgeable science and policy leaders met again at NSF to consider the great wealth of information and ideas that had accumulated during that period, and to envision the opportunities and challenges that nanoscience and nanotechnology would present in the coming years. The meeting was sponsored by the Nanoscale Science, Engineering, and Technology Subcommittee (NSET) of the U.S. National Science and Technology Council's Committee on Technology, and it has recently published the major findings and recommendations of the 10 topical task forces that were organized in this large and complex meeting: Productivity and Equity; Future Economic Scenarios; The Quality of Life; Future Social Scenarios; Converging Technologies; National Security and Space Exploration; Ethics, Governance, Risk and Uncertainty; Public Policy, Legal and International Aspects; Interaction with the Public; Education and Human Development [2] (also included as Vol. I of this book).

The participants prepared drafts of their contributions before the meeting, but then revised them in response to what they learned from the rich exchange of information and insights, with the constant encouragement of the editors. As a result, the 48 essays have stronger intellectual connections than conference papers usually do, as well as greater depth. They range from rigorously factual reports of recent developments, to well-informed projections of trends, to visionary outlines of what the technology could mean in future years.

These individual contributions support the conclusions and recommendations of the 10 task forces [2]. These include the need for clear, scientifically grounded statements of the principles of nanotechnology to enable non-scientists to participate effectively in public policy discussions. Participants strongly recommended supporting a broad range of research studies at the nanoscale, selected primarily from peer-reviewed investigator-initiated proposals and evaluated with public involvement. They judged that research will be needed on the human health and environmental consequences of nanostructured materials and that government will need to review the adequacy of the current regulatory environment for nanomaterials, given the existence of size-dependent properties.

Another point of consensus was that a careful and rigorous analysis of the adequacy of current NNI funding levels and of future investment priorities is

M.C. Roco and W.S. Bainbridge (eds.),
Nanotechnology: Societal Implications — Individual Perspectives, 1–5.

necessary to optimize societal benefit. Participants were especially concerned about the need for educational reforms not only to teach principles of nanoscience and nanotechnology to students at many levels, but also to support cross-disciplinary training, to equip underutilized scientists and engineers with nanotechnology-related skills, and to train social scientists and other scholars to conduct science and technology studies related to the field. Enthusiasm was also expressed for research and development partnerships linking industry, academia, national laboratories, U.S. funding agencies, and corresponding international organizations.

The essays in this volume do far more than merely support such recommendations. They also outline a complex agenda for future research, offer creative ideas for policy initiatives or industrial entrepreneurship, and inform the reader about vast possibilities for future human progress. Although the 10 task force areas were an excellent rubric for organizing input to the formal recommendations, we found that the individual contributions best fit a seven-part categorization: economic impacts including commercialization, social scenarios charting alternate paths for the future, converging technologies, ethical or legal issues, appropriate governance mechanisms, public perceptions of the science and technology, and educational issues such as curriculum development and multidisciplinarity. Brief descriptions of the seven sections of this volume follow.

1. Economic Impacts and Commercialization of Nanotechnology

A good beginning has been made on developing methods and databases to chart the growth of nanotechnology-based industries. Pressing challenges include the need to identify the best innovation models for management, the processes that will provide essential human resources, and the most informative measures of success. Some participants believed that the value of nanoscale and nano-enabled innovations would be great enough to support a distinctive nanoeconomy. More specifically, the economic growth and improvement of human life attributable to information technology depends on continued improvement in microelectronics, which has recently entered the nanoscale and must become nanoelectronics. Larger questions concern the sustainability of economic growth stimulated by nanotechnology and its benefit for the wages of workers.

2. Social Scenarios

Although one cannot accurately predict the future of any technology, it will be necessary to develop ways of identifying likely possibilities in order to anticipate ethical issues, based on multiple points of view, metaphors, contexts, and timeframes. For example, nano-enabled, mobile information technology will allow people to record all their experiences, thereby increasing many opportunities for personal fulfillment while raising a privacy issue for the people with whom the individual interacts. The question often will be not how a given nanotechnology will affect otherwise stable conditions, but how it will interact with the chaotic forces that swirl in an already unstable world, such as the impending population collapse in postindustrial nations caused by insufficient fertility. Sometimes, a conceivable but unproven nanotechnology application might have tremendous impact, however; for example some analysts think it may be possible to create general-purpose fabricators capable of producing many valuable products from readily available materials locally at low cost. Many other issues deserve analysis, such as whether nanotechnology really will contribute to broader prosperity, whether it will encourage research universities to emulate commercial enterprises, what new possibilities it will open for artists, and how we can actually arrive at an appropriate vision of its potential.

3. Converging Technologies

Nanotechnology will have much of its effect on humans in partnership with other technologies, notably biotechnology, information technology, and new technologies based on cognitive science [3]. Examples include molecular machines comparable to the natural machinery inside living cells, medical devices and materials that might be implanted inside the human body, and the application of principles from computerized natural language processing to genomics and proteomics. The complexity of such multidisciplinary innovation will make it difficult to distinguish real risks from phantom risks in practical contexts such as product liability law. Convergence of historically distinct sciences and branches of engineering is not an automatic process, and it may be difficult to achieve because the communities involved are culturally heterogeneous and may unnecessarily defend their professional autonomy. At the same time, convergence of technical disciplines at the nanoscale will be essential for society, for example, by providing the knowledge and the tools for environmental protection.

4. Ethics and Law

There is general recognition of the importance of incorporating an ethical consciousness throughout the process of nanotechnology innovation, rather than waiting until an innovation has been deployed and reacting belatedly to the consequences. However, a vigorous debate concerns the proper roles of professional ethicists in this process, with some participants doubting their objectivity and technical competence. The conference itself illustrated the important roles that academic philosophers can play, raising issues that others had overlooked, stressing values like transparency in public decision-making, and sharpening conceptions of the quality of life. Among the challenges for law and government regulation are establishing consistent definitions of terms, finding ways to make sure that courts benefit from the necessary technical expertise, and ensuring that the patent system protects intellectual property rights in an era when the technical realities are changing rapidly.

5. Governance

In the modern world, government not only regulates the applications of technology but also invests in the fundamental scientific research that makes it possible in the first place. Comparison with past examples, such as nuclear power or genetically modified organisms, can alert one to issues that may arise, without providing perfect guidance for managing development to maximize human benefit. The multidisciplinary field of Science and Technology Studies needs to apply increasingly improved research methodologies to a growing range of questions about nanotechnology. Some of the implications of government action may be indirect, such as the way in which large-scale funding initiatives transform the goals and functioning of universities. Given the heightened concern for national security at the present time and the dual-use nature of nanotechnologies that have military applications, policy debates in the defense area will be both complex and crucial.

6. Public Perceptions

For the interests of the general public to be represented in the making of public policy and investment strategies concerning nanotechnology, public perceptions of the field could be decisive. It is difficult to communicate about risks, especially when the probability of harm and its degree of severity cannot be estimated, and when the general public has its own ideas about how frightening an imaginable but improbable accident might be. Research on the actual likely societal impact will be useful, as will studies of how the mass media are reporting nanotechnology, and of how relevant social movements muddy the waters with hyperbole. However, public involvement cannot be a one-way street, in which our only responsibility is to make sure that correct information flows to the public. Rather, the public must be fully engaged, with ample opportunity to express its concerns and state its goals for the technology.

7. Education

In significant measure, nanoscience and nanotechnology education is a human resources challenge, because an unknown but probably large number of scientists, engineers, and other skilled workers will be required for economic progress, national security, and new frontiers such as space exploration. Both by its own nature and through convergence with other fields, nanotechnology is inherently multidisciplinary, which means that many students must be trained to be interactional experts mediating between disciplines. New nanoengineering curriculum will also be needed, as well as new interactive learning environments to help students visualize reality at the nanoscale. Some knowledge about nature at the nanoscale must be incorporated in even the earliest school grades. Many non-technical advanced students will need to learn about nanotechnology, and future nanoengineers will need to study the ethical and societal implications of their work.

Research on the societal implications of nanoscience and nanotechnology has only just begun, but the 48 essays offered here demonstrate that already it has discovered some valuable findings, that rich theory to guide research already exists, and that a solid basis has been prepared for rapid progress. The insights collected in this volume will be of value for scientists, engineers, students, policy makers, journalists, investors, and anyone who wants a clear view of the remarkable future made possible by humanity's new power to understand and create at the nanoscale.

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1. Economic Impacts and Commercialization of Nanotechnology

SOCIO-ECONOMIC IMPACT OF NANOSCALE SCIENCE: INITIAL RESULTS AND NANOBANK

Lynne G. Zucker and Michael R. Darby, UCLA [1]

Research on the nanoscale has revolutionized areas of science and has begun to have an impact on, and be impacted by, society and economy. Early traces of these processes are already available to us, and we are capturing these data in NanoBank now before the ephemeral traces are lost to the social science and ethics research communities. NanoBank is a large- scale, multi-year project to provide a data resource for social scientists, ethicists, nanoscientists, government officials, and the public. NanoBank will hold data elements that document the socio-economic impact of nanoscience and nanotechnology, and institutional change that occurs either to support the development or as a response to it. The research of the discovering scientists, those who learn from them, the nonprofit organizations that assess risks and/or benefits of the new technology, and the process of industry formation will be documented. NanoBank traces the knowledge flows that underlie these changes, with special emphasis on cross-discipline flows and flows that transfer knowledge from discovering scientists to scientists working in firms. We begin the early part of the process of disseminating findings based on NanoBank in the figures included in this report.

The U.S. government has identified nanoscience and nanotechnology as a scientific and technological opportunity of immense potential, formally launching a National Nanotechnology Initiative (NNI) in January 2000. It is difficult to define simply the full range of nanoscience, but the NNI's steering committee settled on a definition of nanotechnology that incorporates the scale ("approximately 1–100 nanometer"), the understanding, creation, and use of novel properties and functions that occur at the nanoscale, and the integration into larger scale assemblies [1]. Roco, Williams, and Alivisatos; Siegel, Hu, and Roco; Roco; and Roco and Bainbridge [2, 3, 4, 5] provide a thorough review of the present state of nanoscience and technology, the implementation of the NNI, and an introduction to thinking about the implications of nanoscience and technology for our economy and society in the context of international developments in nanoscale research and commercialization.

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[1] This research is supported by National Science Foundation Grant SES 0304727 (as a Nanoscale Interdisciplinary Research Team project), University of California's Industry-University Cooperative Research Program, UCLA's International Institute, and the Harold Price Center for Entrepreneurial Studies at the UCLA Anderson School.

M.C. Roco and W.S. Bainbridge (eds.),
Nanotechnology: Societal Implications — Individual Perspectives, 7–74.

Our Approach

"Technology transfer is the movement of ideas in people" (Donald Kennedy, Stanford University, March 18, 1994).

NanoBank is built on three insights into the processes of knowledge transfer, commercialization, and industry change. Turning first to knowledge transfer, scientific breakthroughs often yield new knowledge that is initially tacit—not yet codified. New codes and formulae describing breakthrough discoveries often develop slowly—with little incentive if value is low and many competing opportunities if high. This tends to keeps the knowledge tacit.

Second, those with the most information about breakthrough discoveries are the scientists actually making them, so there is initial scarcity: Scientists must learn the new knowledge from the discoverer or someone trained by the discoverer, limiting diffusion [6]. The combination of scarcity and tacitness yields natural excludability, a barrier to the diffusion of the valuable knowledge. Indeed, cooperation by the inventor is required for successful commercialization by the licensee for 71 percent of the inventions licensed at universities [7, 8, 9, and Table 7.1].

Third, commercialization of scientific breakthroughs requires access to naturally excludable knowledge, both tacit and scarce, that constitutes intellectual human capital retained by the discovering scientists. Thus, top scientists become the main resource around which firms are built or transformed in both biotechnology [10, 11, 12] and nanotechnology [13]. Top discovering scientists who collaborate with company scientists have strong positive effects on company success that increases as the extent of involvement goes up [14, 15].

Technological change at any given time is highly concentrated in a relatively few firms in a few industries [13, 16]. This metamorphic progress dramatically transforms existing industries, forms new industries, or both. It is misleading to concentrate on the many firms in many industries achieving perfective progress through gradual improvement or inching up. To understand or affect technological progress we must focus on the exceptions—the industries and firms achieving metamorphic progress.

The source of the driving innovations for metamorphic change may be internal or external to the industry, with external innovations using different technological bases the most threatening to existing firms in a transforming industry [17]. Biotechnology transformed the pharmaceutical industry, and nanotechnology also uses different technological bases likely to transform industries—but it is too early yet to identify which industries will experience the largest impacts. In both cases, natural excludability of breakthroughs gives discovering and other top scientists and engineers a key role and increases the likelihood of metamorphic change.

In this chapter, we report preliminary results based on core data files from an early pre-beta test form of NanoBank that focuses on nanoscale research and commercialization—an area with dramatic, recent breakthrough academic discoveries and evidence of likely metamorphic industry change. For purposes of comparison, we will refer to biotechnology, which is a well-studied recent and