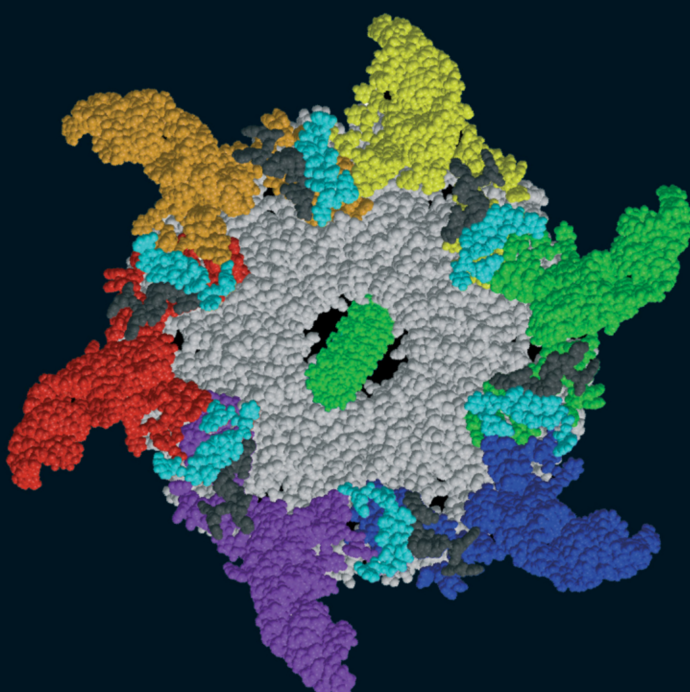
Managing Nano-Bio-Info-Cogno Innovations

Converging Technologies in Society

William Sims Bainbridge and Mihail C. Roco (Eds.)



Springer

A C.I.P. Catalogue record for this book is available from the Library of Congress.

ISBN-10 1-4020-4106-3 (HB)
ISBN-13 978-1-4020-4106-8 (HB)
ISBN-10 1-4020-4107-1 (e-book)
ISBN-13 978-1-4020-4107-5 (e-book)

Published by Springer,
P.O. Box 17, 3300 AA Dordrecht, The Netherlands.

www.springer.com

Printed on acid-free paper

Printed in the Netherlands.

1. PROGRESSIVE CONVERGENCE

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Abstract: This introductory chapter briefly defines the "NBIC" unification that is rapidly taking place today among Nanotechnology, Biotechnology, Information technology, and Cognitive science. It then describes how the other chapters address the potential impacts of converging technologies, considers how innovation can be stimulated and steered, and provides a basis for an understanding of the societal implications of NBIC.

Introduction

At this point in history, tremendous human progress becomes possible through converging technologies stimulated by advances in four core fields: Nanotechnology, Biotechnology Information technology, and new technologies based in Cognitive science (NBIC). Many individual authors had noticed the gathering convergence of technical disciplines, and sociobiologist E. O. Wilson wrote an especially influential 1998 book on the emerging harmony among the sciences. However, convergence became especially visible, and scholarship about its causes and consequences became very active, through a major 2001 conference, sponsored by the U.S. National Science Foundation and Department of Commerce, that resulted in a substantial book (Roco and Bainbridge, 2003). The intellectual basis of convergence was strengthened by three further annual conferences held in Los Angeles in 2003, New York City in 2004, and near Kona, Hawaii, in 2005. The Los Angeles meeting resulted in a second book (Roco and Montemagno, 2004), and this third volume is an outgrowth of the New York conference. The question raised at the first conference – "if visionary activities related to NBIC would have impact?" – has been replaced in the following meetings with "how and when?" – aiming at anticipatory measures for taking advantage better, sooner and in a responsible way for society.

The effort springs from an ongoing attempt to understand the societal implications of nanoscience and nanotechnology, which was energized by a 2000 conference organized by the National Science Foundation at the request of the National Science and Technology Council (NSTC), Subcommittee on Nanoscale Science, Engineering, and Technology (NSET), and the resultant book (Roco and Bainbridge, 2001). Subsequently, a number of workshops and publications have achieved progress in this area (Roco, 2002, 2004, 2005; Roco and Bainbridge, 2002, 2005; Bainbridge, 2003, 2004; Miller,

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[1] Any opinions, findings, and conclusions or recommendations expressed here are those of the authors and do not necessarily reflect the views of NSF.

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2003; Nordmann, 2004; Radnor and Strauss, 2004). NBIC convergence is much more than merely an adjunct of the nano revolution in science and engineering, but it draws great strength from the concurrent and synergistic breakthroughs achieved in the four domains of NBIC in recent years.

Nano-Bio-Info-Cogno Unification

Technological convergence is progressive in two important senses of the term. First, the NBIC fields are in fact progressively merging, step by step, and apparently at an accelerating rate. Second, the unification of the great realms of technology will promote human progress, if they are applied creatively to problems of great human need. Indeed, unless convergence takes place, in both the technical and social realms, it is hard to see how humanity can avoid conflicts, such as those that marred the 20th century, caused by limited resources for available technology and social differences within each county and globally. Only by moving to a higher technological level will it be possible for all of the peoples of the world to achieve prosperity together without depleting essential natural resources to the point at which the future of civilization itself is in doubt.

The great convergence that is taking place today should not be mistaken for the mundane growth of interdisciplinary or multidisciplinary fields. For many decades, small-scale convergence has taken place in areas such as astrophysics, biochemistry, and social psychology. However significant these local convergences have seemed for the scientists involved in them, they pale in comparison with the global convergence that is posed to occur in the coming decades. It will constitute a major phase change in the nature of science and technology, with the greatest possible implications for the economy, society, and culture.

NBIC convergence requires, and is made possible by, the radically new capabilities to understand and to manipulate matter that are associated with nanoscience and nanotechnology. The integration of technology will be based on the unity of nature at the nanoscale, as well as an information system that would cross disciplines and fields of relevance. Conventionally defined as the size range from 1 to 100 nanometers – from 1/1,000,000 to 1/10,000 of the thickness of an American dime – the nanoscale is where complex molecules form, where the building blocks of living cells are structured, and where the smallest components of computer memories and processors are engineered. Remarkably, many of the key structures of the vast human nervous system exist at the nanoscale, such as the vesicles that store neurotransmitters, the gap between neurons across which those neurotransmitters flow, and the pigment molecules in the eye that make vision possible. Recent advances in nanoscience and nanotechnology enable a rapid convergence of other sciences and technologies for the first time in human history.

Many of the most powerful developments in biotechnology and biomedicine are taking place at the nanoscale. This is true not merely in genetic engineering (with DNA molecules about 3 nanometers in width), imaging (with quantum dots of few nanometers), targeted drugs (with nanoparticles as carriers), and biocompatible prosthesis (with molecules "by design") – but also in those many branches of biotechnology where improved understanding of the processes that give life to cells would be advantageous. Thus, much biotechnology today – and increasingly more in the future – is a variant of nanotechnology. Beginning students of chemistry are often perplexed when they learn that organic chemistry does not necessarily depend upon biology, because the term refers to a broad class of complex molecules that need not have been produced by living organisms. Synthetic biology and engineering of nanobiosystems are recently introduced terms. Because both nanotechnology and biotechnology often deal with complex molecules, tools and concepts developed in one can be applied in the other, facilitating convergence.

Modern information technology is based on microelectronics, which is rapidly evolving into nanoelectronics. As a first step, computer chips are manufactured by processes such as photolithography that deposit many thin layers of substances on the chip, then etch away unneeded areas. The layers on the chips, as well as the layers on magnetic disks that store data, have become nanoscale thin, and this very thinness gives them unique electric properties. The current advances on nanolayers with special insulation or conducting properties will evolve to three-dimensional nanostructures and devices and may lead to replacing the information carrier from electron charge to new carriers such as electron spin, photon, or quantum state. Recently, the width of the transistors on a chip has also moved into the nanoscale, with some being only 50 nanometers wide. Currently, researchers are exploring a number of avenues for achieving molecular computing – such as building transistors out of carbon nanotubes – that could form the basis of a new generation of computing, achieving much greater information densities and processing speeds with significantly reduced power requirements. At the same time, progress in nanotechnology and biotechnology is dependent upon constantly improved sensing instrumentation and information processing capabilities. Furthermore, hierarchical system approaches with emerging behavior originating from the nanoscale will require new simulation capabilities, and large databases and computers will allow quantitative evaluation of interdependent technological, economic, and social phenomena.

Of the four NBIC fields, cognitive science is the least mature, but for this very reason, it holds very great promise. This is a multidisciplinary convergence of cognitive and perceptual psychology, linguistics, cultural anthropology, neuroscience, and artificial intelligence aspects of computer science. The incomplete nature of this local convergence is suggested by the fact that to date sociology and political science have not participated significantly in the development of cognitive science, even though many sociologists and political scientists study the formation and transmission of knowledge, belief, and opinion. Although parallel work is being done in economics, much is only loosely connected to cognitive science. Clearly, neuroscience and artificial intelligence tie cognitive science to biology and to information science, but links to nanoscience are also visible on the horizon, both through the emerging understanding of the functions of neurons on the nanoscale and through new nano-enabled research methodologies for studying the brain and human-tool/machine interaction.

As cognitive science matures, it not only gains more and more opportunities for convergence with other sciences but also becomes a solid basis for a range of innovative new technologies advancing individual and group creativity. Human intellectual and social performance will be greatly enhanced by nano-enabled, portable information systems and communication devices, by biotechnology treatments for disorders of the mind or memory, and by increased understanding of how the human brain and senses actually function.

All branches of science and technology may be converging, but NBIC convergence is especially influential. These are major domains, each with huge power to transform human life. Nanotechnology and information technology are enablers, as well as creative fields in their own right, giving other branches of science and technology new powers. Biotechnology and cognitive science directly concern the human body and mind and have the greatest possible implications for human physical and mental health.

Exploring NBIC Innovations

The individual chapters in this book, supplemented by the three appendices, sketch many of the potential impacts of converging technologies, consider how innovation can be stimulated and steered, and provide a basis for an understanding of the societal implications.

Guidance for planning the future is provided in the next four chapters by Mihail C. Roco, Richard E. Albright, James Canton, and Evan S. Michelson. Roco focuses on policies for research and development investment that will drive technological progress in a manner that maximizes human benefit, and on the need for new business models. His chapter provides a practical guide for achieving the idealistic goal of bettering the conditions of human life. Albright offers a specific conceptual tool for planning and anticipating the future, in the form of roadmaps that articulate strategic definition, research direction, technology, and an investment or action plan. Canton argues that

NBIC convergence is integral to an economy based on innovation, and the basis for future energy resources, health care, and the quality of life. With an eye to policy implications, Michelson shows how NBIC convergence can be measured in terms of government spending, university programs, inter-firm strategic alliances, intra-firm technological expansion, and patent citations.

The next group of three chapters focuses on the human challenges we must overcome in order to achieve convergence. Michael E. Gorman and James Groves explain the problems faced when scientists and students from different fields attempt to collaborate, and they draw lessons from their own experience of solving such problems. Thomas A. Finholt and Jeremy P. Birnholtz report the social and cultural difficulties that computer scientists and earthquake engineers experienced in building a collaboratory, and they outline principles that might avoid problems in future projects when a transforming tool like information technology is applied to the needs of a domain of science. Jim Hurd looks beyond the laboratory, and indeed beyond the industrialized world, to describe the powerful mixture of entrepreneurship and idealism that will be required to put NBIC technologies in service of the citizens of developing nations.

Four chapters examine the tremendous opportunities and ethical challenges that arise when convergence gives a prominent role to human biology, especially the brain. James R. Baker explores the diversity of ways in which nanotechnology may provide new diagnostic and therapeutic techniques for intervention with environmental disorders, developmental diseases, and degenerative diseases. A team represented in the NBIC conferences by Wolfgang Perod describes the groundbreaking research that members are doing in developing computational architectures on the basis of detailed examining of the connections between neurons in the functioning mammalian brain. Wrye Sententia analyzes the competing rhetorics that people use in debating the ethics of cognitive enhancement, focusing on the near-term example of pharmaceutical methods for improving human memory. Zack Lynch offers an analytical classification of sectors of a new, emerging industry he calls neurotechnology, that will be made possible as nanotechnology and information technology assist biotechnology in enhancing human brain functions.

Three chapters explore the partnership between information technologies and new technologies based on the cognitive and social sciences. Robert St. Amant explains the principles of human-computer interaction that allow designers to create information systems that best empower, inform, and enable people to achieve their goals. William Sims Bainbridge considers how cognitive technologies can enhance human performance and well-being, focusing on two examples: an artificial intelligence personal advisor, and dynamic lifetime information preservation systems. A team led by Jim Spohrer outlines the shape and purpose of a new, convergent scientific discipline that must be created, largely rooted in the union of information technology with cognitive science, to allow the services industries to serve their customers to maximum advantage.

The four concluding chapters consider the social, legal, and ethical implications of converging technologies. George Khushf employs philosophical methods to examine the ethical issues associated with the accelerating rate of NBIC technological development and the goal of enhancing human performance. Sonia E. Miller warns that the current legal system is poorly prepared to cope with scientific evidence in an era of converging technologies and urges people both inside and outside the legal profession to take personal responsibility for improving this situation. James J. Hughes uses the instructive example of biotechnology to survey the competing technology-related ideologies that are emerging and that will play an ever-more-important role in the politics of the 21st century. Bruce E. Tonn considers the significant social changes that might result from NBIC convergence, notably the possibilities for increased local self-sufficiency, establishment of non-spatial governments, transformation of people's identities, and emergence of diverse new cultures across the planet.

The three appendices provide perspective on the potential future applications of Converging Technologies, the scientific work currently in progress that will accomplish NBIC, and the questions that must be answered if industry and other societal institutions are to be able to manage the converging new technologies.

References

Bainbridge, W. S. 2003. Converging technologies (NBIC). Pp. 389–391 in *Nanotech 2003: Technical Proceedings of the 2003 Nanotechnology Conference and Trade Show.* Boston: Computational Publications.

Bainbridge, W. S. 2004. Converging technologies. Pp. 126–133 in W. S. Bainbridge (ed.), *Berkshire Encyclopedia of Human-Computer Interaction*. Great Barrington: Mass.: Berkshire.

Miller, S. E. 2003. Converging technologies: Innovation, legal risks, and society. *Risk Management Newsletter* 1(3): 1, 5–7.

Nordmann, A. (ed.). 2004. *Converging Technologies – Shaping the Future of European Societies.* European Commission, www.ntnu.no/2020/final_report_en.pdf.

Radnor, M., and J. D. Strauss, (eds.), Commercializing and Managing the Converging new Technologies, Northwestern University, 2004.

Roco, M. C. 2002. Coherence and divergence in science and engineering megatrends. *Journal of Nanoparticle Research* 4: 9–19.

Roco, M. C. 2004. Nanoscale science and engineering: Unifying and transforming tools. *AIChE Journal* 50(5): 890–897.

Roco, M. C. 2005. Environmentally responsible development of nanotechnology. *Environmental Science and Technology*, March 1: 106–112A.

Roco, M. C., and W. S. Bainbridge (eds.). 2001. *Societal Implications of Nanoscience and Nanotechnology*. Dordrecht, Netherlands: Kluwer.

Roco, M. C., and W. S. Bainbridge. 2002. Converging technologies for improving human performance: Integrating from the nanoscale. *Journal of Nanoparticle Research* 4(4): 281–295.

Roco, M. C., and W. S. Bainbridge (eds.). 2003. *Converging Technologies for Improving Human Performance*. Dordrecht, Netherlands: Kluwer.

Roco, M. C., and W. S. Bainbridge (eds.). 2005. *Societal Implications of Nanoscience and Nanotechnology (II)*. Report for National Nanotechnology Initiative. Washington, D.C.: National Science and Technology Council.

Roco, M. C., and C. D. Montemagno (eds.). 2004. *The Coevolution of Human Potential and Converging Technologies*. New York: New York Academy of Sciences (Annals of the New York Academy of Sciences, vol. 1013).

Wilson, E. O. 1998. *Consilience: The Unity of Knowledge*. New York: Knopf.

2. THE EMERGENCE AND POLICY IMPLICATIONS OF CONVERGING NEW TECHNOLOGIES

Mihail C. Roco, National Science Foundation, and Chair of the U.S. National Science and Technology's Subcommittee on Nanoscale Science, Engineering and Technology[1]

Abstract: After a brief overview of the general implications of converging new technologies, this chapter focuses on its effects on research and development (R&D) policies and business models as part of changing social relationships. These R&D policies will have implications on investments in research and industry, with the main goal of taking advantage of the transformative development of NBIC. Development of converging technologies must be done with respect for immediate concerns (privacy, toxicity of new materials, unified nomenclature, etc.) and longer-term concerns including human integrity, dignity, and welfare. The efficient introduction and development of converging new technologies will require new organizations and business models, as well as solutions for preparing the economy, such as multifunctional research facilities and integrative technology platforms.

Introduction

Science based on the unified concepts on matter at the nanoscale provides a new foundation for knowledge creation, innovation, and technology integration. The term *convergent new technologies* refers to the synergistic combination of nanotechnology, biotechnology, information technology, and cognitive sciences (NBIC), each of which is currently progressing at a rapid rate, experiencing qualitative advancements, and interacting with the more established fields such as mathematics and environmental technologies (Roco and Bainbridge, 2002). It is expected that converging technologies will bring about tremendous improvements in transforming tools, providing new products and services, enabling human personal abilities and social achievements, and reshaping societal relationships.

Our core idea is to advance an integrative approach for converging science and engineering from the nanoscale, information, and system levels with a refocus on human needs and aspirations. Those needs and aspirations are identified in the development of the biomedical and cognitive areas. Control of matter at the nanoscale and developments in systems approaches, mathematics, and computation allow us for the first time to understand that the natural world and scientific research are closely coupled, complex

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hierarchical systems. Implications of converging new technologies would be in key areas of human activity, including:

- Revolutionary tools and products
- Everyday human performance, such as work efficiency, accelerated learning, and increase of group performance
- Changing organizations and business models, policies for reshaping the infrastructure, setting priorities for R&D planning, and other societal relationships; establishment of NBIC science and technology platforms and facilitating the coevolution of new technologies and human potential are envisioned
- Moving toward a "universal information domain of exchange" for ideas, models, and cultures.

Examples of new products and services are pharmaceutical genomics; neuromorphic technology; regenerative medicine; biochips with complex functions; multiscale molecular systems; electronic devices with hierarchical architectures; software for realistic multiphenomena and multiscale simulations, processes, and systems from the basic principles at the nanoscale; new flight vehicles using biomimetics; and quantitative studies with large databases in social sciences. Cognitive sciences will provide better ways to design and use the new manufacturing processes, products, and services, as well as leading to new kinds of organizations, societal interactions, and cultural traits. A survey on potential future applications of converging new technologies is given in Appendix 1.

The National Science Foundation (NSF), the National Aeronautics and Space Administration (NASA), the Environmental Protection Agency (EPA), the Department of Defense (DOD), and the Department of Energy (DOE) have several R&D projects in the area of converging technologies. These projects are at the confluence of two or more NBIC domains, such as developing neuromorphic engineering, improving everyday human performance, "learning how to learn," and preparing for societal implications of converging technologies. Industry involvement is evident in seed projects and in the R&D strategic plans of several companies. Ethical and other societal implications must be addressed from the beginning of any major converging technologies program. User- and civic-group involvement is essential for taking better advantage of the technology and developing a complete picture of its societal implications. We need a systematic, deliberate, and responsible approach.

After a brief outline of the key areas of relevance of converging new technologies, this chapter evaluates key societal relationships that would be affected by NBIC.

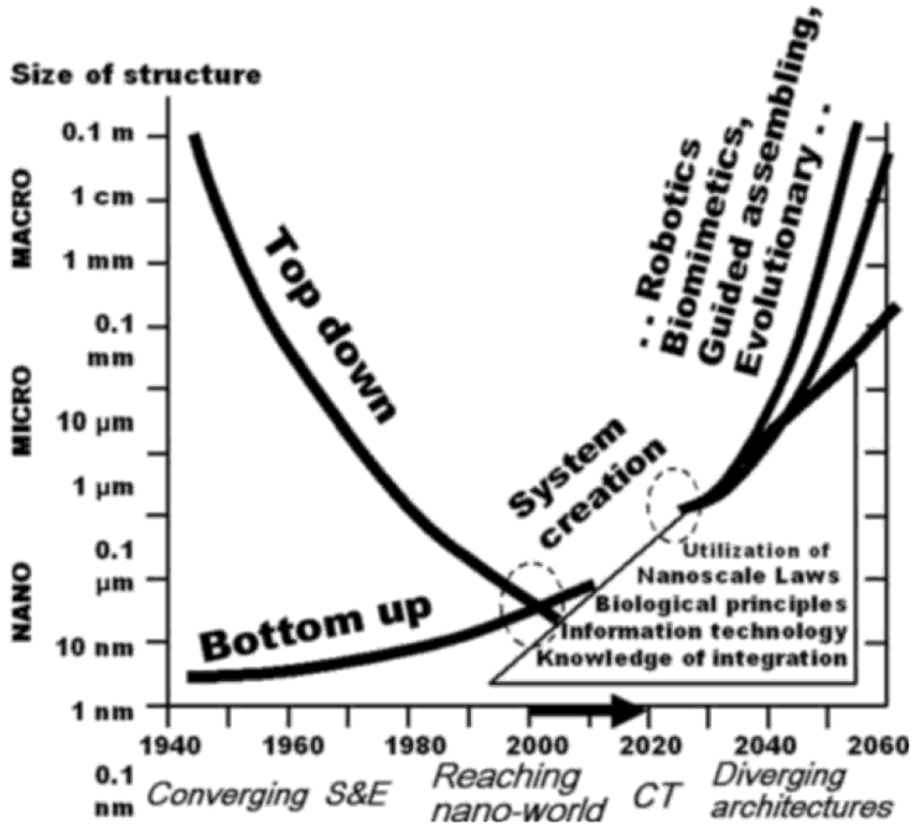
Divergence, Convergence, and Integration in Science and Engineering

There is a longitudinal process of convergence and divergence in major areas of science and engineering (Roco, 2002). For example, the convergence of sciences at the macroscale was proposed during the Renaissance, and it was followed by narrow disciplinary specialization in science and engineering in the 18th through the 20th centuries. The convergence of understanding at the microscale (modeling and simulation by simple components) for various disciplines was advanced in the 19th century, and it was followed by the divergence of various computational platforms such as finite elements and finite differences. The convergence at the nanoscale reached its strength in about 2000, and we estimate that there will be a divergence of the nanosystem architectures in the next decades. The gap between various technological developments and their societal acceptance, and the digital versus analog electronic platforms, are divergence examples. Current convergence at the nanoscale and the information level are happening because of the respective use of the same elements of analysis (i.e., atoms/molecules in nanotechnology or bits/parts in information technology) and of same principles and tools, as well as because of our ability to make cause-and-effect connections from simple components to higher-level architectures. In both nano and information realms, the respective phenomena/processes cannot be separated, and there is no need for discipline-specific averaging methods.

There are various dimensions and scales for convergence. In 2000, convergence had been reached at the nanoworld (Figure 1) when typical phenomena in material nanostructures could be measured and understood with a new set of tools and seen as the basics in biological systems, nanomanufacturing, and communications. Another convergence is expected to be reached on system creation using NBIC in about 2020; building systems from the nanoscale will require the combined use of nanoscale laws, biological principles, information technology, and system integration. The research focus will shift toward networking at the nanoscale and multiscale architectures, artificial tissues and sensorial systems, quantum interactions within nanoscale systems, development of human cognitive potential, knowledge integration, and establishing a universal domain of information exchange for human activities. Molecules will be used as devices, and from their engineered-structure architectures there will emerge fundamentally new functions that will be exploited in information, biological, and thinking systems.

Research will include (a) atomic manipulation for design of molecules and supramolecular systems, (b) controlled interaction between light and matter with relevance to energy conversion among others, (c) exploiting quantum control mechanical–chemical molecular processes, (d) nanosystem biology for health care and agricultural systems, (e) human–machine interfaces at the tissue and nervous system level, and (f) convergence of NBIC domains. Then, after 2020, one may expect divergent trends as a function of the system architecture. Several possible divergent trends are system architectures based on: 1) guided molecular and macromolecular assembling; 2) robotics; 3) biomimetics; and 4) evolutionary approaches.

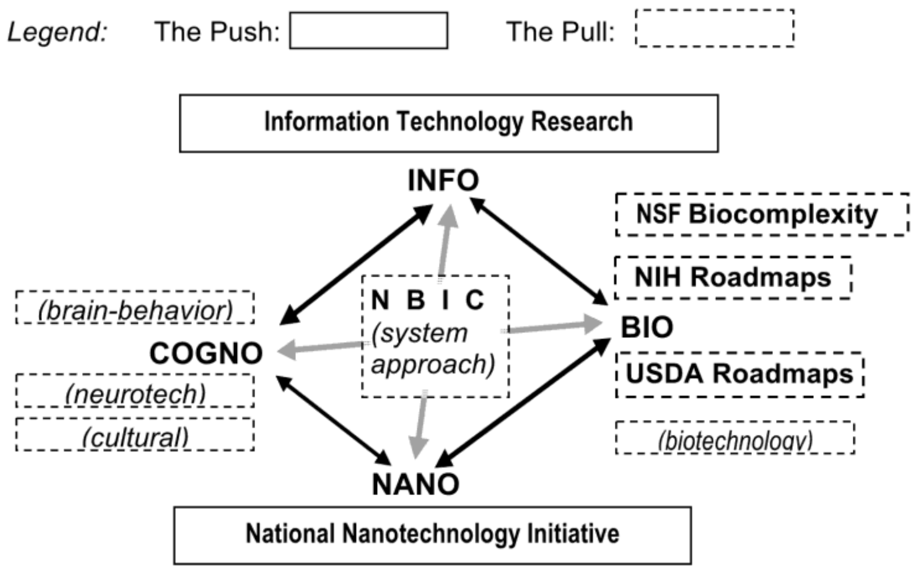
Figure 1. Reaching the Nanoworld (~2000) and NBIC Methods for System Creation from the Nanoscale (2000–2020)



A defining trend in science and engineering is the NBIC convergence that will take place in the first part of the 21st century and that will affect social relationships. The transforming effect on society is expected to be large not only because of the high rate of change in each domain and their synergism with global effect on science and engineering but also because we are reaching qualitative thresholds in the advancement of each of the four domains. Nanotechnology is reaching the foundation of all manmade and living systems, we move toward molecular medicine and nanobiosystems design, information technology begins to handle sufficiently large databases for quantitative evaluations of societal studies, and we begin to connect physico-chemical phenomena of the brain with behavior.

In the United States, we have started two national initiatives on Information Technology Research (ITR in 1999, about $2B in FY 2005) and National Nanotechnology Research (NNI in 2000, reaching about $1.2B in FY 2005), as outlined in Figure 2. (In the diagram, the "push" refers to already-defined programs, whereas the "pull" refers to programs yet to be defined.) Converging Technologies was originally conceptualized as a successor to NNI based on the exploitation of the unity of nature and manmade things at the nanoscale. It is also a potential joint successor of NNI and ITR, as the latest projects funded under ITR would indicate (Appendix 2).

Figure 2. NBIC Transforming Tools: R&D Programs, 2000



ITR and NNI provide the technological "push" with broad science and engineering platforms. Realizing the human potential, "the pull" would include the biotechnology and cognitive technologies.

Several topical, agency-specific programs have been initiated in the field of biotechnology, such as the National Institutes of Health's (NIH) Roadmaps (including genome), NSF's Biocomplexity (in 2000), and the U.S. Department of Agriculture's (USDA) roadmap. There has been no national initiative on biotechnology and no large-scale programs on cognition, except for the core research programs in the Directorate for Social, Behavioral, and

Economic Sciences at NSF. There was a need to balance this situation. In 2003, the Human and Social Dynamics NSF priority area was launched, funded at over $20M per year. No special interagency program has been established based on the systems approach or cognitive sciences. The NBIC focus aims to balance the R&D portfolio while maintaining other programs.

The convergence is taking place on the broad scale (including anthropology, environmental research, up to and including social studies), but the most dynamic component driving an accelerating path is NBIC. Reports that focus on NBIC as the emerging core of all converging technologies are

- *Coherence and Divergence in Megatrends in Science and Engineering, 1999–2000* (Roco, 2002)
- *Societal Implications of Nanoscience and Nanotechnology* (Roco and Bainbridge, 2001)
- "Converging Technologies for Improving Human Performance" (Roco and Bainbridge, 2002)
- *The Coevolution of Human Potential and Converging New Technologies* (Roco and Montemagno, 2004)
- Interagency Conference on Research at the Interface of the Life and Physical Sciences (Swaja *et al*., 2005)
- *Commercializing and Managing the Converging new Technologies* (Radnor and Strauss, 2004; see Appendix 3 of this volume)
- Bylaws of the International Risk Governance Council (IRGC, 2004)
- This volume (*Managing Nano-Bio-Info-Cogno Innovations*, 2006)

The broad NBIC opportunities and the need for measures that are anticipatory – that is, learning before doing, with deliberate and "upstream" choices in research, production, and public policies – and corrective – because all events are part of a complex societal system, the evolution of which is not deterministic – have been identified in the two previous volumes (Roco and Bainbridge, 2003; Roco and Montemagno, 2004).

The 2001 workshop in United States has been followed by other workshops that were at least partially inspired by similar ideas in Canada and Asia (Korea, Japan, Taiwan) since 2003 and in Europe (EC, UK, Spain, Netherlands) since 2004 (Nordmann, 2004). Several non-governmental organizations expressed support, and others expressed concerns about the fast pace of change if societal implications are not properly considered (ETC, 2003; Wilsdon and Willis, 2004). Although the approach in Asia is more proactive for technological advancements, the workshops in Europe have been focused more on societal implications.

This chapter outlines current NBIC research trends and their implications and focuses on policy and business implications. The main NBIC implications are

- Expanding human cognition and communication
- Improving human health and physical capabilities
- Enhancing societal outcomes, including new products and services
- Changing societal relationships, including reshaping models for business and organizations, revising policies for R&D investments and infrastructure, creating science and engineering platforms
- National security
- Unifying science and education

Policy Implications of NBIC for R&D and New Investments

Reaching toward the building blocks of matter for all manmade and living systems with a broad nanotechnology platform makes the transforming tools more powerful and the unintended consequences more important than for other technologies. The integration of nanotechnology with biotechnology, information technology, and cognitive sciences increases the transforming power and potential risks even further. A main concern is a possible instability in human development, because (a) perturbations are created at the foundation of life, and (b) the transforming tools may create perturbations that could be difficult to be controlled after the fact. This underlines the need for an anticipatory and corrective approach in addressing societal implications for each major R&D program or project. In this framework, we have identified several policy challenges of NBIC:

1. Establishing a broad and long-term S&E and infrastructure framework for accelerated techno-economical development using NBIC. One must ensure the availability and synergism of investigative tools, knowledge creation, and production methods supporting various NBIC components. For example, large companies, or groups of smaller companies, would need to develop laboratories and facilities with multidisciplinary NBIC expertise to efficiently engineer and develop new products.

2. Support NBIC integration though long-term strategic planning for each major trend (e.g., NNI, ITR, Biomedical; challenges: cognition, integration), and systematically address the R&D gaps. To systematically address the scientific, technological, and infrastructure development challenges, it is necessary to establish a coordinating group, involving academia, industry, and government and civil organizations.

3. Prepare the technology NBIC S&E platforms, through priorities of infrastructure investments and production incentives. Such platforms are already in development at several companies (such as General Electric) and

government laboratories (such as Sandia National Laboratories). One must include development of nomenclatures, definitions, and regulatory measures.

4. Reduce the usual delay between technological development and societal response. The risks of S&E developments should be evaluated in the general context of potential benefits and pitfalls in the short and long terms. Harmonious introduction of technology should address societal acceptance and the dialog with the public to minimize the delay between research and commercialization in response to societal needs.

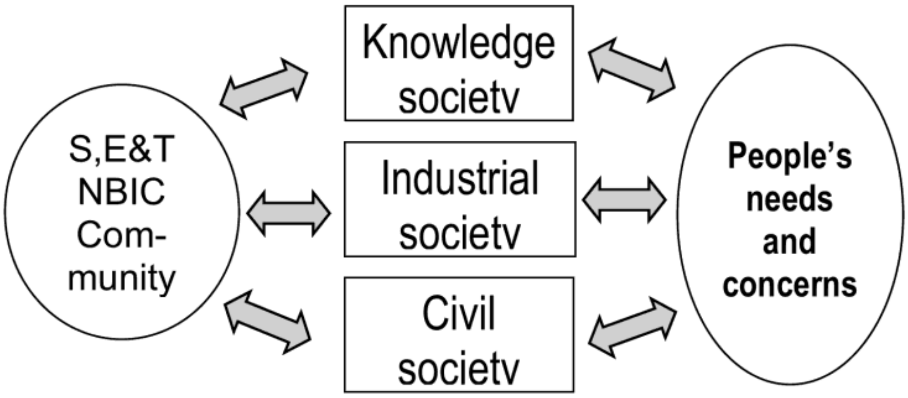
5. Identify new evaluation criteria to include the NBIC contribution in the national infrastructure. The criteria of progress must include infrastructure accumulations, increments in citizen education and training, improved working capabilities, and quality of life.

6. Responsible development of NBIC includes respect for human nature, dignity, and physical integrity. The coevolution of society and converging new technologies based on nanoscale control is a main goal. Right to welfare (quality of life, long-term health and safety issues) and access to knowledge must be respected. Several groups call for cultural changes and an international "code of conduct." There is growing interest concerning the gap between developed and developing counties and how nanotechnology may bring benefits to the underdeveloped regions. In the shorter term, immediate issues on environmental, health, and safety must be addressed in research, societal studies, regulatory measures, and government policies. The International Risk Governance Council (IRGC, 2004) is an example of the international organizations aiming to address overarching risk assessment and management issues. IRGC goals are to develop an independent methodology framework for risk management as well as the principles for "good governance" for consideration by the national governments and international organizations. The people's needs and concerns should be addressed from various perspectives: knowledge society (intellectual drive), industrial society (help industry and other productive means), and civil society (help societal goals, civil society goals), as outlined in Figure 3.

7. Revise earlier education and training. A key challenge for converging technologies development is the education and training of a new generation of skilled workers in the multidisciplinary perspectives necessary for rapid progress of the new technologies. Interdisciplinary connections reflecting unity in material and information worlds need to be promoted. Coherent science and engineering education and training must be introduced from kindergarten to continuing education, and from scientists to non-technical audiences that may decide the use of technology and its funding. Science and humanity curriculum should be connected in a logical and holistic manner. At the college level, one should encourage convergent programs such as interdisciplinary capstone seminars, double majors, and undergraduate involvement in real research (e.g., the Research Experiences for

Undergraduates activities sponsored by the National Science Foundation). Today, only in their last years of their Ph.D. programs do students begin to understand the broader connections among various domains of learning. An alternative would be to provide freshmen and sophomore students with unifying concepts for matter, information, and biology systems, and then

Figure 3. Addressing People's Needs and Concerns



advance with studying various disciplines that focus on phenomena and averaging methods for related length scales. In this way, one could move the same basic concepts from one field to another and create a synergistic view for potential applications in various areas of relevance. Reversing the pyramid of learning would provide a coherent view and motivation to students in physical, chemical, biological, and engineering sciences at all levels.

8. Promote academe-industry-government partnering in advancing NBIC. A successor program combining the tools and ideas developed by the NNI and ITR programs in collaboration with industry and academia, with a focus on people's needs and aspirations in biomedical and cognitive domains, is recommended for accelerated progress in converging technologies.

9. Develop anticipatory responses in the legal system and patent system, and inform the public "up-stream" about the science and technology discoveries (Roco and Bainbridge, 2002; Nature, 2004). Anticipatory measures should address ethical, legal, socio-economic, and political aspects. For example, the new discoveries about brain research and human development in conjunction with converging technologies must be considered in developing and applying the laws, instead of the precedent-seeking legal decisions. The scientific evidence involving complex NBIC issues is increasing in importance in courts and must be considered following rigorous rules for testimonies and expert witnesses (Miller, 2005).

10. Use global context and partnerships. Collaboration with civic and professional societies is necessary in addition to the usual research, development, and production partnerships. For example, the recently founded Converging Technologies Bar Association[1] brings together scientists, engineers, lawyers, and policy makers with the following goals:

- Dialog with legal community, public awareness
- Education and reference material for the legal system
- Source of information on implications of NBIC
- Support creation of converging technologies corridors
- Advocate policies, regulations and legislation.
- Anticipatory measures for the implications of NBIC

Changing Organizations and Businesses

The combined application of NBIC technologies, eventually integrated from the nanoscale and information levels with more traditional technologies, will require availability of specific measuring, design, and manufacturing tools in production clusters under new organization business models. Several ideas for reshaping business and organizations are

- New concept for NBIC technology platforms. Because similar NBIC principles and tools will be applied to various applications, it is expected that multidisciplinary R&D platforms would be developed for multiple areas of relevance. Clusters of "technology parks" are envisioned. Production requiring knowledge and manufacturing will be performed in clusters for integrative technology platforms.
- In order to increase productivity, it is expected that production (manufacturing, energy production, etc.) increasingly will be distributed geographically and on demand, as a function of users' needs and local production potential. For example, using solar energy with high-efficiency nanomaterials would allow decentralization of large energy-conversion units, and self-assembling nanobiodevices using same software distributed in a network would allow decentralized nanomanufacturing. Because of the high-tech and rapid scientific changes, research will be brought closer to technological development and production.
- Current social, education, and organization theories may become irrelevant and must be reformulated.

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[1] www.convergingtechnologies.org

- Distributed and integrated knowledge creation and design methods must be adopted. In addition, the organizations themselves will become distributed.
- Build new interdisciplinary competencies and partnerships. The educational programs will need to prepare people with the new interdisciplinary and collaborative skills.
- The international dimension increases in importance.

A report on implications of converging technologies on business and organizations has been prepared on the basis of the input received at the NSF-sponsored workshop in 2003. The executive summary of the resultant report prepared by the Northwestern University (Radnor and Strauss, 2004) is included as Appendix 3 of this volume.

Key Issues in the Responsible R&D of NBIC in the Short and Long Term

Societal concerns need to be addressed in the R&D of NBIC from the beginning of the research programs. Typical issues in the short term (such as toxicity of nanomaterials and privacy of wireless communication systems) have a different focus than the long-term challenges (which may lead to fundamental changes in society). The convergence of NBIC with the environmental technologies and societal implications studies is essential in addressing these challenges.

Pressing Issues for Responsible Development of NBIC

The immediate and continuing issues need to be addressed concurrently with the development of NBIC R&D projects and the creation of respective products. They may be separated into three groups:

- Environmental, health and safety (EHS) knowledge and measures specific to converging new technologies in both research and industrial units.
- Cross-sectors in economy and internationally accepted nomenclatures, norms, standards and regulations for the development of science, engineering, technology and new markets.
- Management of risk analysis for the private sector and government.

Key Issues in the Long Term

Long-term issues for responsible development of nanotechnology are related to its broader social and economic outcomes, require longer time intervals to be recognized and changed, and must be on the radar of the governments and civic organizations that work to ensure an equitable and responsible growth. Those issues include:

- Respect of human nature, dignity, and physical integrity. The harmonious coevolution of human potential and converging new technologies based on nanoscale, information, and system control is a main goal. Human right to welfare (quality of life, long-term health and safety issues) and access to knowledge must be respected. Several groups call for cultural changes and a "code of conduct."
- Balanced and equitable R&D NBIC investment in society. The investments must be done in such a way that the benefits and secondary consequences are properly distributed in society, including for opportunities for education and training and development of knowledge needed to address EHS.
- Human health and environment protection and improvement. This includes approaches and criteria for sustainable development of technology, energy supply, and transportation, including life-cycle analysis of products, materials flow analysis, clean-up techniques on new principles, weather implications, and other global effects. Examples are environmentally benign manufacturing methods.
- Economic, legal, ethical, moral, and other social aspects to adjust and, when possible, anticipate socio-economic changes caused by converging new technologies. The necessary knowledge should be developed through research, creation of databases, and dissemination, including two-way interaction with the public and various interested organizations.

Closing Remarks

Converging nano-bio-info-cogno (NBIC) in conjunction with more traditional technologies are expected to change the way research, product manufacturing, and education are performed. Furthermore, converging new technologies will affect societal interactions, business models, and R&D policies. Key challenges are

- Creating the multidisciplinary science and technology platforms for NBIC
- Preparing a national effort for earlier NBIC education and training
- Developing hybrid manufacturing and global networking using NBIC advances
- Understanding the nervous system and the connection to mind, behavior, education, and work productivity

- Developing capacity to anticipate and manage future opportunities and risks for deliberate and responsible developments
- Respecting human integrity and dignity
- Considering NBIC implications in large R&D programs and investments
- Suiting demographics and sustainable development
- Cultural implications that would require better public understanding and participation in R&D and infrastructure development decisions

We need to develop anticipatory, deliberate, and proactive societal measures in order to accelerate the benefits of converging technologies. Adaptive and corrective approaches in government organizations need to be established in the complex societal system with the goal of improved long-term risk governance. User- and civic-group involvement is essential for taking better advantage of the technology and developing a complete picture of its societal implications. It is recommended that a multidisciplinary, international forum or a coordinating group be established involving academia, industry, government, and civil organizations in order to better address the NBIC scientific, technological, and infrastructure development challenges. Optimizing societal interactions, R&D policies, and risk governance for the converging new technologies can enhance economic competitiveness and democratization.

References

ETC. 2003. *The Big Down: From Genomes to Atoms*. Winnipeg, Canada: ETC Group.

International Risk Governance Council (IRGC). 2004. *Bylaws*. Geneva, Switzerland: International Risk Governance Council. www.irgc.org/.

Miller, S. E. 2005. Science confronts the law. This volume.

Nature. 2004. Going public (editorial). *Nature* 431: 883.

Nordmann, A. (ed.). 2004. *Converging Technologies – Shaping the Future ofEuropean Societies.* European Commission. www.ntnu.no/2020/final_report_en.pdf.

Radnor, M., and J. D. Strauss, (eds.), *Commercializing and Managing the Converging New Technologies*, Northwestern University, 2004.

Roco, M. C. 2002. Coherence and divergence in science and engineering megatrends. *Journal of Nanoparticle Research* 4: 9–19.

Roco, M. C. 2004. Nanoscale science and engineering: Unifying and transforming tools. *AIChE Journal* 50(5): 890–897.

Roco, M. C., and W. S. Bainbridge (eds.). 2001. *Societal Implications of Nanoscience and Nanotechnology*. Dordrecht, Netherlands: Kluwer.

Roco, M. C., and W. S. Bainbridge. 2002. Converging Technologies for Improving Human Performance. *Journal of Nanoparticle Research* 4(4): 281–295.

Roco, M. C., and W. S. Bainbridge (eds.). 2003. *Converging Technologies for Improving Human Performance*. Dordrecht, Netherlands: Kluwer.

Roco, M. C., and C. D. Montemagno (eds.). 2004. *The Coevolution of Human Potential and Converging Technologies*. New York: New York Academy of Sciences.

Swaja, R., B. Hamilton, K. Dill, C. Fraser, and J. Onuchic. 2005. Conference on Research at the Interface of the Life and Physical Sciences. www.nibib1.nih.gov/Events/110904Conf/interfacereport20405.pdf

Wilsdon, J., and R. Willis. 2004. *See-Through Science: Why Public Engagement Needs to Move Upstream*. London: DEMOS.

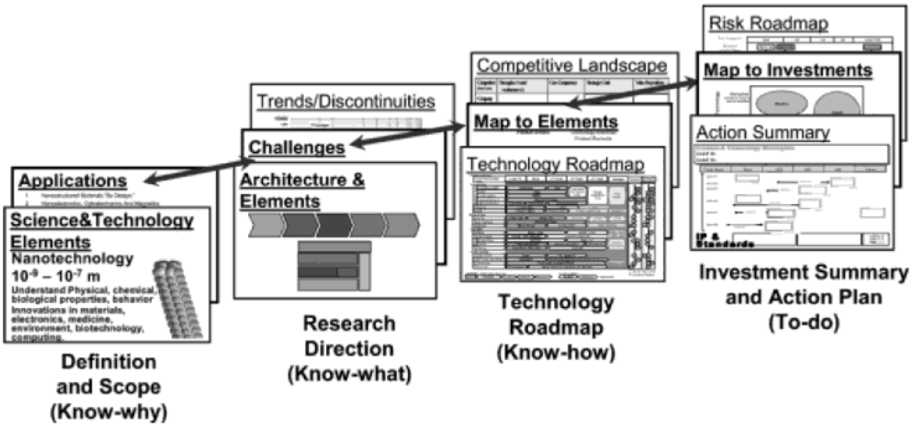
evolution. Corporations and other organizations use roadmapping for a number of purposes such as product planning, platform planning, or organizational capability planning. Product-technology or platform roadmaps lay out the evolution of a product or platform over time. Capability roadmaps define the capabilities needed for success of a services business or for functional organization such as manufacturing or information technology.

Table 1: Roadmapping Topics

	Definition and Strategy: "Know-why"	**Direction: "Know-what"**	**Technology: "Know-how"**	**Action Plan: "To do"**
Science and Technology Roadmaps	Scope of the field; technology applications	Technical challenges; architecture; trends, discontinuities, and objectives	Technology elements and evolution; competitive technologies and costs	Action programs; technology investment; intellectual property and standards; risk roadmap
Industry and Government Roadmaps	Industry structure and position; customer drivers; industry direction	Technical challenges; Architecture; trends and disruptions; learning and targets	Technology elements and evolution; technology alternatives; future costs	Action programs; Technology investment; IP and standards; risk roadmap
Product-Technology and Platform Roadmaps	Market structure and size; customer drivers; competitive strategy	Product roadmap; architecture; product drivers and targets; feature evolution	Technology elements and evolution; competitive position; target costing	Action programs; technology investment; IP and standards; risk roadmap

Figure 1 shows a typical layout of templates for a roadmap, in this case a science and technology roadmap. The template in Figure 1 includes four parts, as defined above. The first part, the definition and scope, covers market and competitive strategy. The second part defines the product direction, the product roadmap. The third part defines the technology evolution, the technology roadmap. Finally, the action plan defines the key programs or projects that will be needed to support the direction, a technology investment summary, and a view of the risks to the plan. Each part is elaborated in a series of pages or panels describing an important element of the plan. The four parts are linked by connecting drivers – customer drivers to product drivers to technology elements to technology investments. In this way the rationale for decisions on directions taken may be tracked in order to conduct a structured review of gaps and develop plans for closing those gaps.

Figure 1. The Four Parts of a Science and Technology Roadmap



Drawing a Convergence Roadmap

The first step in roadmapping is to define the scope. At the highest level, we can begin with some draft definitions of the scope of converging technology fields (NNI, 2003):

- Nanotechnology: Technology related to features of nanometer scale (10^{-9} meters): thin films, fine particles, chemical synthesis, advanced microlithography, and so forth
- Biotechnology: The application of science and engineering to the direct or indirect use of living organisms, or parts or products of living organisms, in their natural or modified forms.
- Information Technology: Applied computer systems – both hardware and software, including networking and telecommunications.
- Cognitive Science: The study of intelligence and intelligent systems, with particular reference to intelligent behavior as computation.

In roadmapping, a team is concerned with understanding and planning for innovations, defined as “the introduction of something new.” For our roadmapping purposes, this is taken to mean new technology put into practice and widespread use. A technology may be invented, but it will not be an innovation until it is widely applied.

Roadmapping should help teams answer questions such as: How will fields interact to create innovations? What innovations will occur and when? What is needed to create innovations? What are gating factors for innovations?

There are many efforts underway, and many more will come, to plan and roadmap within each of the technology fields. We should focus our roadmapping in two areas. First, we should look where innovations occur at the intersections of fields. For example, at the nanoscale, nanotechnology and biotechnology will often be indistinguishable. Second, we should look to innovations in one area that will be enabled by innovations in another. For example, as biotechnology becomes more information intense, it will be enabled by information technology.

Three key supporting elements of a roadmap are applications/needs, architecture, and growth trends.

Applications/Needs

Applications, or customer/market needs, determine drivers for the roadmap. Drivers are usually of the following types: "Do more," "do for less," "do new things," "do enabling things." Applications are often expressed in grand challenges for the field. Two prime examples are the Grand Challenges for the U.S. National Nanotechnology Initiative (NNI, 2003) and the Grand Challenges in Global Health defined by the Foundation for NIH in October, 2003 (FNIH, 2003). Table 2 lists the main NNI challenges and the global health goals with related challenges.

Architecture

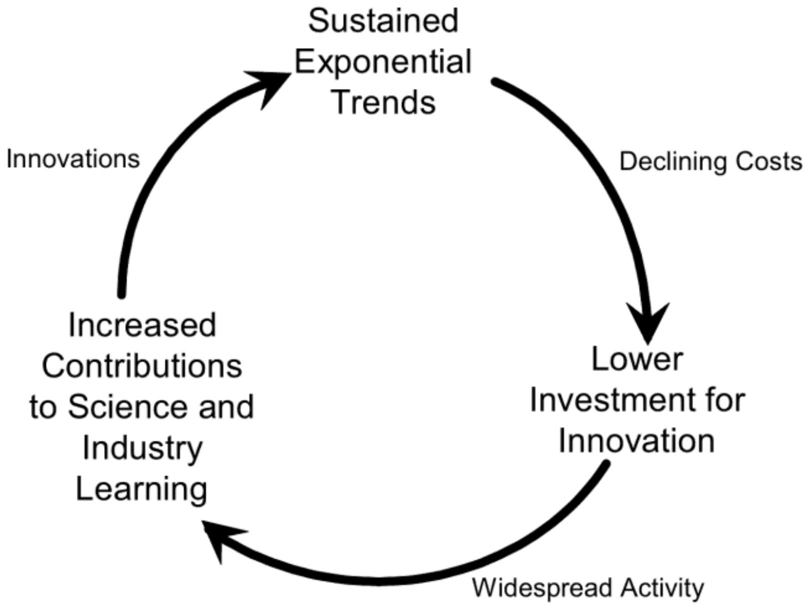
Architecture defines how the pieces of the problem fit together. The architectural elements become the framework for the technology roadmap and help determine the priorities of work to achieve the roadmap's objective. An architecture for roadmapping convergence was suggested by discussion at the Commercializing and Managing the Converging New Technologies workshop described in Appendix 2 of this book and is shown in Figure 2.

Growth Trends

Identification of long-term, sustained growth trends is central to understanding which inventions can become innovations. Trends in enabling technology result in continued declining costs for technology applications and increasing sophistication of applications.

Declining costs of technology allow increasingly complex applications. These trends have been apparent in information technology for more than 40 years. For example, computing power has exhibited exponential growth that began in the 1940s and continues at the present (Albright, 2002b).

Figure 3. The Positive Innovation Loop



References

Albright, R. E. 2002a. Roadmapping for global platform products. *Product Development and Management Association Visions Magazine* 26(4): 19–22.

Albright, R. E. 2002b. What can past technology forecasts tell us about the future? *Technological Forecasting and Social Change* 69(5): 443–464.

Albright, R. E., *et al.* 2003. Technology roadmapping. *Research and Technology Management* 46(2): 26–59.

Foundation for the National Institutes of Health. 2003. *Grand Challenges in Global Health initiative*. Foundation for the National Institutes of Health, www.grandchallengesgh.org.

Kappel, T. A. 2001. Perspectives on roadmaps: How organizations talk about the future. *Journal of Product Innovation Management* 18(1): 39–50.

Kostoff, R. N., and R. R. Schaller. 2001. Science and Technology Roadmaps. *IEEE Transactions on Engineering Management* 48(2): 132–143.

NNI. 2003. *Research and Development Supporting the Next Industrial Revolution*. Supplement to the President's FY 2004 Budget. National Nanotechnology Initiative, www.nano.gov.

Phaal, R., C. J. P. Farrukh, and D. R. Probert. 2001. *Fast Start Technology Roadmapping.* International Association for Management of Technology, www.iamot.org/paperarchive/GSTBB.PDF.

Willyard, C. H., and C. W. McClees. 1987. Motorola's technology roadmap process. *Research Management* 30(5): 13–19.

4. NBIC CONVERGENT TECHNOLOGIES AND THE INNOVATION ECONOMY: CHALLENGES AND OPPORTUNITIES FOR THE 21ST CENTURY

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Abstract: Nano-Bio-IT-Cogno (NBIC) convergence offers both challenges and opportunities for the future of science, industry, and society. NBIC convergent technologies represent a new integrated framework for considering not just how science might be conceptualized but also how socioeconomics might be viewed differently. NBIC convergence is further evidence of an emerging Innovation Economy, where innovation tools, systems, products, and services become the dominant basis for commerce. Economic opportunities generated by NBIC may also improve quality-of-life factors in society. This chapter considers some of the evolving policy, business, and science implications of NBIC as we grapple with the vexing challenges associated with this Innovation Economy. In addition, as-yet-unresolved critical areas of concern – such as access to sustainable energy and health care, both of which are essential to quality of life, business and U.S. global leadership – may be furthered by NBIC convergence. Although NBIC is in the early stages of discovery, relevance of this new holistic model for solving global problems is appealing. The NBIC model holds significant promise in shaping the future development of human potential and fostering appropriate human enhancement. The hope is that NBIC may effectively accelerate the resolution of grand challenges that confront us today and as we move into the 21st century.

Forecasting the Future of NBIC

How should we consider the future of NBIC? Are the innovations that will extend life and health and increase performance part of a new era of human enhancement? Can we discover new sources of energy to improve the quality of life for all? Can industry look to NBIC inventions to accelerate productivity and commerce? The promise is large, and the potential is unlimited. Forecasting the future of NBIC is a daunting challenge, but here is a collection of innovations that may come to pass as we unlock this potential:

- 100,000 machines generating energy from the solar cells that can all fit on the head of a pin
- Autos that are constantly recharging themselves, grown from nano-bio foundries

W.S. Bainbridge and M.C. Roco, (eds.) Managing Nano-Bio-Info-Cogno Innovations: Converging Technologies in Society, 33–45.

- A medical device that produces and dispenses drugs from the host body
- Supercomputers the size of a cell, in every human body, promoting health and preventing disease
- A hydrogen-based energy grid generating abundant clean, renewable energy for the community
- An Internet-based electronic commodities trading market that trades alternative energy credits
- Supply chains that are real-time linked invention powerhouses that globally connect producers to consumers for the on-demand ordering of any "idea product" any time.

Some of these forecasts may seem unrealistic, but I challenge all to consider the radically fast pace of innovation development we have witnessed in the past few years. Science and technology, the basis for all breakthrough innovations, have accelerated to a rapid pace over the past 25 years on a scale no civilization has ever experienced in the history of the world. The Internet was developed rather recently. The human genome has just been mapped. Embedded onboard computers that are wearable are just now available. Ten years ago we did not know what a stem cell was. Today, advanced technology, from IT to biotech and nanotech, are mainstream innovations quickly moving into the marketplace.

It is not hard to speculate about forecasts of smarter, smaller, faster, and more utilitarian products being invented in faster development cycles offering vast new power and a multitude of new capacities many more times what we have access to today. NBIC convergence is one example of this fast evolution of technology.

The central question will remain: Can we use NBIC convergence and evolution to resolve the grand challenges and the big problems that we either face today or will face in the future? This is the authentic challenge we need to meet to create sustainable and prosperous societies, industries, and economies. This should be the greatest challenge every leader in government and industry must be concerned about and working towards resolving every day.

NBIC researchers, using a unified approach for developing entirely new smarter and more intelligent products, could leverage from each of the specific attributes of each of the disciplines to create new combinations with complementary value. In other words, nanoscience using the entire NBIC tool kit might be applied to producing solutions to problems faster and more effectively than we do today, as we are too often dominated by silo thinking, silo education, and silo research and development.

For example, nanoscience representing the reduction of materials that might function on the nanoscale, combined with the organic biomimetic functions that bioscience brings, matched with the information processing and *in silico* modeling contributed by information technology, and finally enabled by cognitive science insight into brain function might bring a new scientific breakthrough that would improve the human condition. If we had focused on only one science, we would have not been able to achieve a breakthrough.

Toward a Systems Approach

What we too often have today is silo thinking in science, as in business and policy development, which offers too little a systems approach to conceptualizing a big enough "big picture" so we may: 1) Understand the larger interdependent, systems-wide factors that create large-scale problems (e.g., energy and health care), and 2) Invent systems-wide solutions that can address these larger problems. Silo thinking has of late, in the business community, come under attack because of the emergence of the connected enterprise that must break down the walls of unawareness. In the business world, silo thinking results in loss of market share, as well as loss of customers and business failure. Customer loyalty and purchasing are the litmus test for business performance and often survival. There is a high price to pay for the inability to change or the lack of innovation found in products and services, both of which are artifacts of the silo thinking of organizations (and people, especially leaders), and that is business failure. The incentives that drive private-sector innovation are real-time, unforgiving, and essentially Darwinian – survival of the smartest.

The life-and-death struggle of corporations is a fast test bed of the need for systems-wide thinking and action, as it is becoming common knowledge that silo thinking in business is the recipe for death. Business ecosystems may be better environments in which to study the need to reduce and eliminate silo thinking than those in science, in which the rigors of survival do not occur in as fast evolutionary cycles. The pressures of a business to generate profits and become sustainable, generating a return on investment, are always a real-time phenomenon. Few scientific organizations suffer the same fate.

The inability of organizations to change, evolve, and adapt is a dominant aspect of today's modern global corporation. The opposite of these phenomena is the capacity for fast change, adaptation, and a systems-wide transparent connected enterprise. The fact that business corporations are vastly different from scientific organizations is less relevant here than how organizations, for profit or not, enable innovation in the culture and use innovation to sustain their survival.

Turning back to NBIC, a conceptualization of new holistic product families with enhanced functionalities may provide insight into what directions toward which we might aspire. The NBIC challenge is to consider entirely new ways to think about problems and, employing the tool set of NBIC, to create entirely new solutions. New NBIC products may combine the unique characteristics of many of the parts, such as

- Self-assembly of cognitive medical devices at the nanoscale that enhance memory
- Biometric-sensitive communications that provide security
- Personalized genomic-pharma solutions that use our brains as drug factories
- Nanoscale engines that clean the environment of pollution and threatening bioagents
- Biosolar cells that generate energy from the sun and distribute energy over personal grids.

NBIC's Grand Challenges of the Future

There are many problems that even an advanced civilization such as ours has been unable to resolve that go to the core of what technology can accomplish in a given time on a global scale. With little hubris, we can safely say that innovation has delivered much new value to improve society. Although we have used innovations to dramatically improve agriculture yields, poverty and hunger still persist on a global scale. Whereas we have perfected the extraction of carbon-based fuels such as oil and gas, much of the world does not enjoy the same benefits as does the West. Although we have marvelous innovations in telecommunications, still only a fraction of the global population has access to the Internet or even to basic telephone communications, let alone the productivity gross domestic product (GDP) boost from information technology that every growing economy needs. I suspect that high teledensity penetration in the population is linked to increased productivity.

Is there a potential that the convergence of key NBIC technologies could alleviate some of these problems and accelerate people's access to sustainable energy, abundant food, and pervasive communications? The social risks associated with not furthering the use of NBIC in sharing the wealth of innovations may destabilize global security in the future. The risks are too high. At the same time, there may be greater opportunities to stabilize regions that have a potential for conflict by providing access to a higher quality of life for the population. NBIC may play a vital role in normalizing markets, communications, and access to commodities and services (health care and energy) that are essential to a better way of life. It should be in the interests of all policy makers to move towards this realization.

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