Chapter 10
Innovative and Responsible Governance of Converging Technologies

Mihail C. Roco, David Rejeski, George Whitesides, Jake Dunagan, Alexander MacDonald, Erik Fisher, George Thompson, Robert Mason, Rosalyn Berne, Richard Appelbaum, David Feldman, and Mark Suchman

10.1 Vision

10.1.1 Changes in the Vision over the Past Decade

In the last 10 years, the following developments have taken place that impact the governance of converging technologies:

- The viability of integrating nanotechnology, biotechnology, information science, and cognitive science (NBIC) has been confirmed in multiple settings since 2001, mostly in a "reactive approach" responding to collaborative opportunities. This NBIC concept has been extended in this study to other converging platforms and to a holistic systematic approach called Converging Knowledge, Technologies, and Society (CKTS).
- There is an increasing emphasis on the roles of innovation (for societal benefit, jobs, and economic competitiveness), sustainability (in energy, health, food, climate change, etc.) and realizing human potential (in education, workforce, aging with

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Corresponding editors M.C. Roco (mroco@nsf.gov) and W.S. Bainbridge (wbainbri@nsf.gov).

M.C. Roco
National Science Foundation, Arlington, VA, USA

D. Rejeski
Woodrow Wilson International Center for Scholars, Washington, DC, USA

G. Whitesides
Harvard University, Cambridge, MA, USA

J. Dunagan
The Institute for the Future, Palo Alto, CA, USA

A. MacDonald
National Aeronautics and Space Administration, Washington, DC, USA

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dignity, economic and legal support of family, etc.) in evaluating emerging new technologies. The combination of multiple emerging fields has enhanced both expectations and capabilities, exemplified by simultaneous advances in imaging, electronics, genetics, brain research, and other NBIC-based technologies; CKTS offers increased means for pursuing such goals. Examples of convergence ecosystems are the Semiconductor Research Corporation, Silicon Valley, and State and regional science and technology (S&T) initiatives.

- Concerns about the impact of new technologies have grown. Three main concerns have been raised: (1) that powerful new technologies such as synthetic biology and quantum information systems pose uncertain transformational impacts for society; (2) that the ethical challenges will be daunting of balancing new capabilities to improve human healthcare against defining limits to human enhancement; and (3) greater recognition by an increasing number and variety of actors of the role that nanotechnology-based environmental, health, and safety (EHS) and ethical, legal, and social issues (ELSI) play in research, regulatory challenges, and governance under conditions of uncertainty and/or knowledge gaps, voluntary codes, and accepted practices.
- Societal implications of emerging and converging technologies are tied to key contextual factors, including changes in demographics, the multiple S&T poles, knowledge and technology transfer from the Western to Eastern hemisphere, and both the nature and the human awareness of the rapid developments that science and society are experiencing. Smaller countries tend to be able to adjust governance faster, e.g., see the South Korea case study, Sect. 10.8.9.
- Two regulatory approaches are developing in parallel: one that is probing the extendibility of regulatory schemes (“developing the science” approach), and one that is developing exploratory (soft) regulatory and governance models that work reasonably well even with insufficient knowledge for full risk assessment.

E. Fisher
Arizona State University, Phoenix, AZ, USA

G. Thompson
Intel, Santa Clara, CA, USA

R. Mason
University of Washington, Seattle, WA, USA

R. Berne
University of Virginia, Charlottesville, VA, USA

R. Appelbaum
University of California–Santa Barbara, Santa Barbara, CA, USA

D. Feldman
University of California, Irvine, Irvine, CA, USA

M. Suchman
Brown University, Providence, RI, USA

- Two international organizations have emerged: the Converging Technologies Bar Association (CTBA 2003, http://www.convergingtechnologies.org/defalt2.asp) and the Society for the Study of Nanoscience and Emerging Technologies (S.Net 2009, http://www.thesnet.net/). There is also an "International Journal of Emerging Technologies and Society" based in Australia: http://www.swinburne.edu.au/hosting/ijets/ijets/. Such relatively modest beginnings for specialized audiences nevertheless have underlined the need for new approaches to converging knowledge and technology, going beyond current methods that are focused on individual disciplines, individual players, or coincidental collaborations.
- Social media are providing new methods for collaboration enabled by converging technologies, e.g., social-media-enabled innovation and development of "leaderless" movements/networks.

10.1.2 The Vision for the Next Decade

CKTS implications are expected to increase significantly in the next decade, with the following characteristics:

- Convergence will contribute to major changes in science, technology, and society, and will become a condition for national but also industrial and human competitiveness. The convergence approach will become increasingly proactive and systemic (decisions taken considering the system as a whole, as compared to a reactive approach based on interaction of system components). New socio-technical convergence platforms of various sizes will emerge. Systematic convergence in knowledge and technology promises to increase the rate of scientific breakthroughs, lead to the establishment of new S&T domains and support growing expectations for human progress, including improved productivity, education, and quality of life.
- A virtual spiral of creativity and innovation evolving in time (see schematic in Fig. 4.1 in Chap. 4) between and within CKTS platforms will be created, along with an increase in the speed of circulation (transfer) of ideas from one field to another. This will have a significant effect on innovation, productivity, and commercialization. It will be a condition of competitiveness for sectors or regions.
- It is expected that society will increasingly guide and authorize the CKTS research and investment agenda through various governance means. This role will increase as scientific knowledge increases quasi-exponentially, technologies enable more powerful tools, population growth coincides with increased expectations for better quality of life, and global competition intensifies. Governance will increasingly shape CKTS for societal progress.
- The roles of individuals in public groups (e.g., entrepreneur/inventor Elon Musk and his company SpaceX) and of public–private partnerships will increasingly

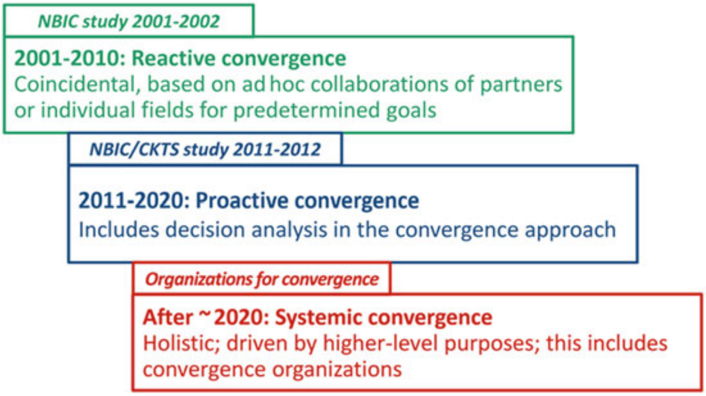

Fig. 10.1 Estimated timeline for progress in converging knowledge and technologies for society. The 2001–2002 study report is Roco and Bainbridge (2003) (Figure courtesy of M. C. Roco)

push the development of new converging technologies, separate from the roles of governments. New tools will emerge for participatory governance, e.g., games, collaborative design, and social media.

- An international community dedicated to these governance considerations is expected to be established, extending efforts already underway within individual emerging technologies. Co-evolution between science, technology, and societal norms and values will become increasingly evident to a larger number of actors.
- CKTS advances will provide improved methods and databases in support of governance.
- The successes of the National Nanotechnology Initiative (NNI) in integrating social science and governance considerations with technology development will be relevant to CKTS.
- The success of CKTS will depend on whether risk governance methods in the short and long terms are addressed from the beginning of each project and whether social scientists and public participants are meaningfully involved.
- A horizontal, vertical, and system-integrated infrastructure will be developed for the essential convergence platforms. Existing and new S&T domains are envisioned to be enabled by CKTS, such as distributed and digital manufacturing, cognitive and neuromorphic engineering, synthetic biology, and quantum information systems. Similar to the case of nanotechnology development, it will become imperative over the next decade to focus not only on how CKTS can generate economic and medical value (“material progress”) and enable *cognitive, social, and environmental value* (“moral progress”), but also on how to contribute to quality of life and how to foster international collaboration.
- Three successive and overlapping steps for convergence of knowledge and technology seem to be emerging on the approximate timeline shown in Fig. 10.1.

10.2 Advances in the Last Decade and Current Status

10.2.1 Innovation and Converging Technologies

This chapter discusses specific aspects of innovation and risk governance of CKTS. By applying the holistic system deductive approach, higher-level language approach, convergence–divergence evolutionary approach proposed in Chap. 4 (see Fig. 4.1), and vision-inspired basic research approach (Fig. 4.5), the CKTS innovation opportunities increase due to the multidisciplinary discoveries within the general convergence platforms, an accelerated innovation process facilitated by the convergence methods, and multisector applications available in the general convergence platforms (see Fig. 10.2). An index of innovation rate (4.1) has been defined by correlation.

The concept of differentiation has been identified as a principle of action in evolutionary society (Parsons and Shils 1951; Parsons 1964) as well as in biological systems. The divergence phase in the convergence–divergence cycle that initially was proposed for the coherent evolution of megatrends in science and technology (Roco 2002) and extended in this volume to evolution of knowledge-centered human activities (R&D, design, production, etc.) has qualitative similarities with the above social science and biological concept.

At the same time, convergence of emerging technologies brings specific kinds of risk challenges:

- Increased technology complexity, uncertainty, and ambivalence in comparison with traditional technologies.

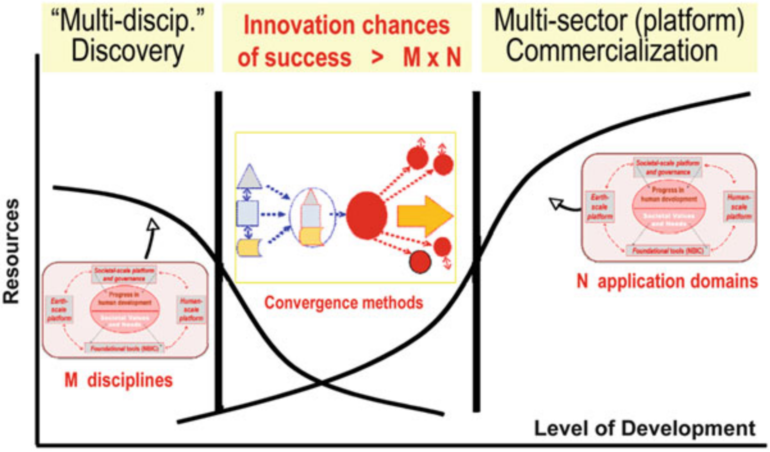

Fig. 10.2 CKTS innovation opportunities increase in proportion with the M number of disciplines supporting the R&D, the N number of application domains, and improvement by applying the convergence methods (overall > M × N). The convergence–divergence approach offers multiple possible pathways from discovery to commercialization (Courtesy of M. C. Roco)

- Interdependency with wide-ranging effects throughout scientific, industrial, and social systems, including convergence and integration trends.
- Increased importance of societal implications, which cannot be fully known at the release of the technology. It will be essential to reduce the time lag between development of scientific knowledge and evaluation of societal implications. Similarly, it will be crucial to integrate anticipation of societal implications with research and development, commercialization, and regulation.

The NBIC technologies have been defined as a multidisciplinary foundational platform for improving the benefits of emerging and converging technologies in society, offering new approaches for education, innovation, learning, and governance (Roco and Bainbridge 2003). As the definition of converging knowledge and technology expands, so do its transforming and risk implications in society. CKTS builds on the convergence process defined within the general platforms of human activities (see Chaps. 1, 2, 3, and 4). Governance of CKTS has many facets, from fostering research to increasing innovation and productivity, to addressing ethical concerns and long-term human development issues (IRGC 2006, 2008). It includes "transformational, responsible, inclusive, and visionary" development, as described below (Roco 2008). The converging technologies approach has been brought to the attention of legislative institutions such as the German Bundestag (Coenen 2008).

10.2.2 Societal Dimensions of Converging Knowledge and Technologies

Principles of holistic interdependence, connectivity, and co-evolution have long-time roots in human civilization (e.g., in ancient oriental cultures, the European Renaissance, and indigenous Indian culture in the Americas). As noted in Chap. 4, in the decade since the first NBIC study was completed, NBIC research programs have been undertaken in the United States, the European Union, China, Russia, Japan, and other countries, as well as by international organizations such as the International Risk Governance Council (IRGC). Converging knowledge and technology bring new opportunities to address societal needs with increasingly more coherent knowledge and technologies.

An international community of scholars who specifically address ethics and societal dimensions of emerging technologies, S.NET, was created in 2009, in part through extension of various national nanotechnology networks (e.g., the National Science Foundation's Nanotechnology in Society Network in the United States, since 2005). Journals such as *NanoEthics* and the S.NET have diagnosed a range of science–society disconnects, from "science leaps ahead/ethics lags behind" (Mind the gap [Mnyuisiwalla et al. 2003]) in about 2000, to "ethics leaps ahead/science lags behind" in 2010. A European Community "Code of Conduct for Research Integrity" has been proposed, but globally, a common terminology and shared levels of national commitment to ethics in R&D are still to be reached. In 2008, the German government evaluated the risks of NBIC (Bundestag 2008).

Public concern over the societal implications of innovative technologies in general is illustrated by ongoing resistance to genetically modified (GM) foods, due in part to the lack of attention to addressing public concerns at the time GM foods were first put on the market in 1996. Critics have continued to object to GM foods on several grounds, including safety issues, ecological concerns, and economic concerns raised by the fact that organisms capable of reproduction are subject to intellectual property law (http://en.wikipedia.org/wiki/Genetically_modified_food). The NNI has explicitly incorporated investment in environmental, health, and safety (EHS) and ethical, legal, and other social issues (ELSI) research to consider and address these kinds of existing and potential public concerns concerning the nation's investment in nanotechnology research.

Development of "leaderless" or "multicentered" movements/networks, in part enabled by social media and converging technologies, is a new phenomenon that has emerged in the last few years.

10.2.3 Governance of Converging Knowledge and Technologies

Challenges to governance of CKTS have included developing the multidisciplinary knowledge foundation; strengthening the innovation chain from priority-setting and discovery to societal use; establishing a common language in nomenclature and patents; addressing broader societal implications; and overall, creating the tools, people, and organizations to responsibly develop and distribute the benefits of the new technologies.

To address those challenges in nanotechnology R&D, *four simultaneous functions of governance* were proposed and have been applied in the United States since 2001 (Roco 2008; IRGC 2008), that it should be

- *Transformative*, including having a results-oriented, project-oriented focus and advancing multidisciplinary and/or multisector innovation
- *Responsible*, including addressing EHS, ELSI, and equity concerns
- *Inclusive*, having all-inclusive, all-agency, and all-stakeholder participation
- *Visionary*, including long-term planning and anticipatory, adaptive policies

Table 10.1 gives U.S. examples of these functions, which have international counterparts.

Growth of converging and emerging technologies research is expected to exceed the average rates of growth in scientific R&D worldwide in the next decade, particularly because of its importance for improving economic efficiency in Western countries and the focus in Asian countries on emerging technologies. Emerging technology areas have been identified in previous chapters of this report, and examples of major emerging technologies in the United States are given in Table 10.2. Other topics such as biofuels, solar energy (photovoltaics), aeolian energy, electric cars, vaccines, cognitive, prosthetics, the game industry, and mass media (networks, twitter, etc.) have more dispersed R&D programs.

Table 10.1 Examples of U.S. governance functions supporting CKTS (2001–2010)

Governance aspect	Example 1	Example 2
TRANSFORMATIVE function		
National and regional investment policies	Support for R&D programs and emerging industries with high economic return and societal relevance (see Table 10.2) Support technologies for renewable natural resources (water, food, energy, environment)	NIH grand challenges set up, and CKTS R&D and facilities developed to address priorities in human health
Science, technology, and business policies	Support for S&T integration in long-term programs (such as Apollo space, nuclear energy, ITR, NNI) through competitive peer-reviewed, multidisciplinary R&D programs	NSF, DOD, NASA support for innovation in converging technologies (nano-bio-info-…)
Education and training	Interdisciplinary Grant for Education, Research and Training (IGERT) program at NSF and NIH	NSF's Science of Learning Centers (addressing topics from brain research to teaching methods)
Technology and economic transformation tools	Support for clusters of manufacturing capabilities for integrated industrial platforms (NRC 2011), such as cell phone technology	Establish research clusters for various emerging areas, such as synthetic biology
RESPONSIBLE function		
Environmental, health, and safety (EHS) issues	The December 2003 Nanotechnology R&D Act includes EHS guidance; OSTP, PCAST, and NRC make EHS recommendations; NNI publishes national nanoEHS strategy in 2008 and 2011	Establish NSTC Emerging Technologies Interagency Policy Committee (2010–) and NSET Nanotechnology Environmental and Health Implications working group (NEHI, 2005–)
Ethical, legal, and social issues and other issues (ELSI+)	Ethics of converging technologies addressed in publications (Roco and Bainbridge 2001, 2007; NGO reports, and UNESCO reports 2006a, b, c)	Program announcements for nano-ELSI (NSF, 2004–); Equitable benefits for developing countries (ETC/NGO 2005; CNS-UCSB 2009)
Methods for risk governance	Risk analysis, including the social context, supported by NSF and U.S. EPA and applied in EPA, FDA, and OSHA policies	Governance for multilevel risk in converging technologies in the global ecological system (IRGC 2008)
Regulations and reinforcement	IT, genome, bio-ethics, and nanotechnology-focused regulatory groups created at NSTC, EPA, FDA, and NIOSH	Voluntary measures for nanotechnology EHS at EPA, 2008

Communication and participation	Increased interactions among experts, users, and public at large via public hearings	Public and professional society participation in legislative processes for IT, genome, and NNI funding
INCLUSIVE function		
Partnerships to build national capacity	NSTC investment in IT, global climate change, robotics, and nanotechnology; e.g., fostering interagency partnerships (27 agencies); industry-academia-state-Federal government partnerships (NNI support for 4 regional-state-local nanotech. workshops)	Partnering among research funding and regulatory agencies in the NSTC for dealing with nanotechnology implications; e.g., the NSET Subcommittee and its NEHI Working Group
Global capacity	International Dialogue Series on Responsible Nanotechnology (2004, 2006, 2008); OECD and ISO working groups on various emerging technologies	International Risk Governance Council reports on emerging technologies; e.g., on nanotechnology, and on food and cosmetics (IRGC 2009)
Public participation	Public debates on human enhancement capabilities and transhumanism caused by human-technology co-evolution (ELSI issues) (Hamlett et al. 2008)	Combined public and expert surveys; public deliberations; informal science education (e.g., NSF programs beginning in ~2001)
VISIONARY function		
Long-term, global view	U.S. strategic plans for space, nanotechnology, information technology, health research, and neurosciences	Long-term effects of technology on human development (*Humanity and the Biosphere*, Foundation for the Future, UNESCO 2007)
Support human development, incl. sustainability	Research on energy and water resources using nanotechnology (DOE, NSF, EPA, others)	Research connecting brain functions, mind, and education (NSF, NIH)
Long-term planning	Ten-year vision statements published for 2001–2010 (published in 2000) and 2011–2020 (Roco et al. 2011) (Similar long-term R&D planning in EU, Korea, Singapore, Japan, China, and other countries)	NNI strategic plans every 3 years (last three in 2004, 2007, and 2010), followed by PCAST and NRC evaluations

Acronyms: *ISO* International Standards Organization, *ITR* Information Technology Research, *NEHI* Nanotechnology Environmental and Health Implications Working Group, *NIOSH* National Institute of Occupational Safety & Health, *NRC* National Research Council, *NSET* Nanoscale Science, Engineering and Technology (Subcommittee of OSTP's Committee on Technology), *NSTC* National Science and Technology Council (U.S.), *OECD* Organization for Economic Co-operation and Development, *OSHA* Occupational Safety and Health Administration, *OSTP* Office of Science and Technology Policy of the White House, *PCAST* President's Council of Advisors in Science and Technology, *UNESCO* United Nations Educational, Scientific and Cultural Organization

Table 10.2 Examples of emerging technology programs in the U.S. since 1950 with timelines

Emerging technology	First commercial prototypes	Expected to reach large-scale application	Related chapters/sections in this report
Nuclear energy	1957	1965	Section 9.8.2
Space: NASA program; unmanned autonomous systems in aerospace	1961	1970	Section 10.8.1
Supercomputers	1980	2000	Chapters 1 and 7
Large databases	1985	2010	Chapter 1
Genetics: genome program	2000	2020	Chapter 5
Nanotechnology	2000	2020	Chapter 1
Smart mobile phones (iPhone)	2005	2010	Sects. 1.1.1 and 4.3.5
Systems and synthetic biology	2010	2025	Chapter 1, Sect. 1.8.3
Robotics for personal service	2010	2040	Chapters 2 and 7, Sects. 2.3.1, 2.8.5, 6.3.1, 7.8.2
Neurotechnology	2010	2060	Chapter 6

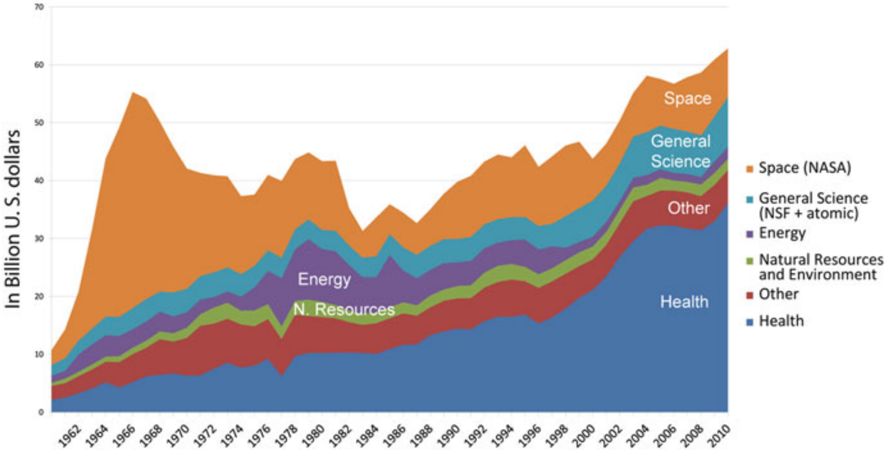

Fig. 10.3 U.S. Federal Government science R&D investments in major areas of focus in the last 50 years, in fixed 2010 U.S. dollars (Figure by M. C. Roco; data source: http://www.whitehouse.gov/sites/default/files/omb/budget/fy2014/assets/hist09z8.xls)

The proportions for R&D investment have changed over time and by country. Such changes in time are relevant to the convergence–divergence process in S&T. Figure 10.3 provides figures for U.S. Government R&D investment between 1960 and 2003. The proportion of health R&D has increased, while the funds remaining for other areas, including emerging technologies in space, energy, and general sciences, have decreased.

Ethical (ELSI), EHS, and public engagement aspects are still being defined for CKTS, but the attention paid to these aspects has increased. Specific aspects related

Table 10.3 Websites with ELSI content related to CKTS

Center	Website
Center for Nanotechnology in Society at Arizona State University	http://cns.asu.edu
Center for Nanotechnology in Society at University of California, Santa Barbara	http://www.cns.ucsb.edu/
Socio-Technical Integration Research (STIR), Arizona State University	http://cns.asu.edu/stir/
Museum of Science, Boston	http://www.mos.org/
Wikipedia	http://en.wikipedia.org/wiki/

to the role of equity in a connected society have been raised (Chinni and Gimpel 2010; Sunstein 2009). Prospects for regulation and legislation are low for the entire range of fields, even if regulations may be developed for various sectors of emerging technologies as the science and applications are better defined. Despite their importance, aspects related to nomenclature, standards, legislation, and policies yet have to receive adequate attention. International interactions are essential in this exploratory phase of the development of CKTS.

Addressing human development and global grand challenges are important goals of CKTS. Several reference websites are given in Table 10.3.

10.2.4 Return on Investment from Emerging Technologies

Emerging technologies have the promise to bring higher than normal returns on public and private investment because of their transforming and disruptive nature. Such returns also depend on the general socio-economic, private sector–public partnerships, governance methods, and international context. The return on material progress has to accompany efforts to advance moral progress. Below are three illustrations of government investment, in information technology, the Human Genome Project, and the National Nanotechnology Initiative. Space (Sect. 10.8.1) and nuclear energy (Sect. 9.8.2) programs are discussed elsewhere in this report.

The IT-intensive "information-communications-technology-producing" industries grew a total of 16.3 % and contributed nearly 5 % to the overall U.S. gross domestic product (GDP), according to estimates for 2010 by the U.S. Bureau of Economic Analysis (2011). A 2011 study by the McKinsey Global Institute (Du Rausas et al. 2011) found that in 2009, Internet-related activities alone contributed an average of 3.8 % to the U.S. GDP. In comparison to this return on private sector and public investment, the total Federal funding in fiscal year 2010 for networking and IT research and development programs was approximately $4.3 billion, just under 0.03 % of GDP. The return on investment in knowledge areas broadly speaking (nanotechnology, genome, space, nuclear, etc.) is broad and difficult to estimate in product returns only. The direct economic benefits listed above generally do not capture the societal benefits realized from the enabled application of other emerging and converging technologies. The investment of the Federal Government in basic research has been recognized as essential (NRC 2012).

The Human Genome Project (HGP)'s $3.8 billion U.S. Government investment from 1988 to 2003 helped, together with private sector investment, to drive $796 billion in economic impact ($796 billion/ $3.8 billion = 210 times) and the generation of $244 billion in total personal income, according to a study released by Battelle (2011). In 2010 alone, human genome sequencing projects and associated genomics research and industry activity directly and indirectly generated $67 billion in U.S. economic output ($67 billion/$3.8 billion = 18 times in 2010) and supported 310,000 jobs that produced $20 billion in personal income. Genomics-enabled industry also provided $3.7 billion in Federal taxes during 2010 (Battelle 2011).

The U.S. National Nanotechnology Initiative (NNI) has stimulated considerable research in nanotechnology, but its broader economic impacts elude calculation because the field is broad and it is difficult to separate the impact of Government-only R&D investment. With a worldwide public and private investment in 2010 of $18 billion (of which $11 billion was public), the market for nanotechnology products reached $300 billion (Roco et al. 2011). In the United States alone, an investment of $4.1 billion (of which $1.8 billion is from Federal/NNI funds) has led to the production of $110 billion of nanotechnology-enabled products representing over 220,000 jobs (Roco et al. 2011). Without including the operation expenses in production, the annual return is about 110/4.1 or ~25 times that for the U.S. nanotechnology R&D investment and 300/18 or ~17 times that for the world. The average growth of markets and numbers of people involved in nanotechnology from 2001 to 2010 has been about 25 % worldwide (Roco et al. 2011; Roco 2011; PCAST 2012).

The goal of nurturing science discoveries into innovative technologies and products has been pursued by the U.S. Federal Government for decades. The President's Council on Bioethics was established under the National Science and Technology Council (NSTC) of the White House Office of Science and Technology Policy (OSTP) in 2001, replacing an earlier group focused on science. An interagency program on Network and Information Technology Research and Development (NITRD) was created in 1991. The year 2001 saw the creation of the NNI, a prototypical experiment in integrating and synergizing a broad-scale program that engaged multiple academic disciplines and multiple government funding agencies and envisioned widespread technology impacts. While the NNI has had its limitations, it is considered by many to have been successful in fostering the incorporation of multidisciplinary perspectives as well as in making strides in dealing with societal concerns. Cognitive neuroscience is the focus of the U.S. BRAIN initiative (Brain Research through Advancing Innovative Neurotechnologies) which began formal interagency collaboration in April 2013.

Previous evaluations of the impact of science and technology generally have concluded that 50–85 % (an average of 67 %) of increase in productivity and economic progress in the United States and other developed countries is due to science and technology (Solow 1957; PCAST 2012). Better integration of knowledge, technology, and society are expected to improve such results.

Because NSF's traditional panel review of proposals may underestimate interdisciplinary, innovative ideas (high-return, high-risk proposals), in 2011 NSF began experimenting with new approaches to proposal evaluation under the umbrella of Integrated Support Promoting Interdisciplinary Research and Education (INSPIRE); the initial program in this effort is the Creative Research Award for Transformative Interdisciplinary Ventures (CREATIV; http://www.nsf.gov/od/oia/creativ/). NSF has also introduced expanded programs to foster international collaborations.

A growing number of universities have created innovation programs and centers that simultaneously address the scientific and technical transition of a university's discoveries into commercial products and preparing students with the business skill sets necessary to accomplish commercialization. Examples include the Martin Trust Center for MIT Entrepreneurship (1958; http://entrepreneurship.mit.edu/), Stanford's Epicenter (http://epicenter.stanford.edu/; "creating a nation of entrepreneurial engineers"), Berkeley's Lester Center for Entrepreneurship (http://entrepreneurship.berkeley.edu/), Carnegie Mellon's Robert Mehrabian Collaborative Innovation Center (http://www.cmu.edu/corporate/partnerships/cic/), and the University of Southern California's Stevens Center for Innovation (http://stevens.usc.edu/).

10.3 Goals for the Next Decade

10.3.1 Advance Innovation for Economic Productivity

Key ideas are:

- *Supporting innovation* enabled by convergence. New models of facilitating innovation will have to develop that are suitable to a diversity of S&T converging inputs and divergent application outputs.
- *Developing common languages* for communication and standards across general convergence platforms for enabling innovation across areas.
- *Creating capacity to address EHS and ELSI* concerns related to rapidly evolving converging knowledge and technology, and to do so in an integrated way that enables enhancements in both innovation and public value.
- *Placing special emphasis on advancing investment in R&D for emerging technologies* as compared to investing in classical S&T fields. Several Asian countries in the last two decades have increased their CKTS investments—partially using basic research from the West.

Gordon (2012) wrote about the "end of progress" thesis (or the average slowdown of innovation in society), which does need to be considered in the context of current debates about economic policy and public investments. His paper questions the assumption that economic growth is a continuous process that will persist forever (Gordon 2012, 1). There was virtually no growth before 1750 (see Fig. 10.4), and there is no guarantee that growth will continue indefinitely. If indeed the current

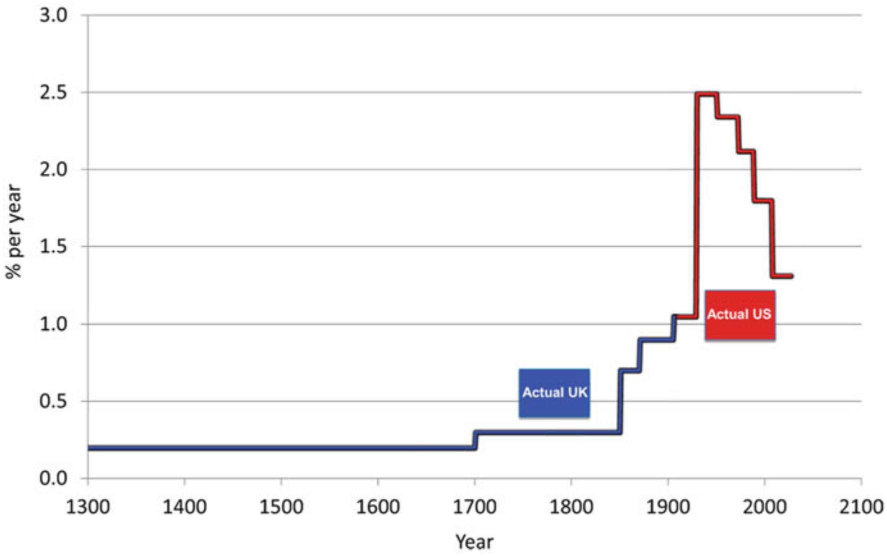

Fig. 10.4 Growth rate in real GDP per capita in the last eight centuries showing "Actual UK" and "Actual US" growth (Gordon 2012, Figure 1; Courtesy of R. J. Gordon)

economic problems are "structural" or the indirect result of decelerating scientific progress, then many of the very expensive proposed solutions will fail. Rather, we must vigorously support work in two kinds of scientific research and engineering innovation: (1) transformative emerging areas like nanotechnology where the possibilities for progress have not yet been exhausted, and (2) efforts to understand the socio-economic consequences and integrate the socio-economic projects aligned with CKTS.

The Gordon thesis is challenged by the position expressed in the *Economist* (2013) that sees the increase in productivity in waves connected to the introduction of a major technology. As an illustration, introduction of electricity after 1890 and of information technology after 1970 correlate with doubling the U.S. labor productivity in about 40 years (*Economist* 2013, Figure 4). In our opinion, convergence would provide the next wave in the conditions of limited natural and investment resources.

10.3.2 Support Converging Technologies to Advance Human Potential and Quality of Life

Key ideas are:

- *Creating new governance arrangements and organizations dealing with CKTS and global issues long-term* is an essential goal for advancing human capacity (enhanced productivity, learning, active aging) and life security (sustainability, health, security). This is aligned with the general CKTS goal of increasing the focus on people.

- *Extending governance of emerging technologies to include broader public(s)* by expanding public participation and adding suitable governance criteria such as sustainability at local and global levels; access and equity; evaluation of causal relations within the societal system; and managing Earth systems.
- *Redesigning foundational governance systems dealing with long-term and global issues.*
- *Building governance structures (personal and social) that account for the neurological and cognitive biases of the brain.*
- *Addressing ethical issues specific to CKTS* related to human enhancement, human–machine interactions, risk of transhumanism, dislocations in the work force, cost of healthcare, and equal rights and opportunities.

Governing the impact of CKTS on quality-of-life indicators in order to limit the risks and maximize the benefits for people and the environment can take numerous forms, including institutional guidelines, regulations, rules, codes, and laws to monitor and manage the development of converging technologies. Meanwhile the deployment of converging knowledge and technologies can also shape the task of (re)designing foundational governance systems.

With the rapid pace of change and innovation occurring in science and technical applications, government and industry officials face an ever-growing challenge to develop effective standards and regulations in the rapid time frames staked out by today's innovation environment. Legal standards and codes are being ported over from legacy models of science and technology and uncomfortably applied to new business and research models, creating a Procrustean bed of confusion that can impede progress. Given the challenges that governments face in dealing effectively with the pace and complexity of scientific innovation at present, much less the long-term impacts, global issues such as climate change suggest that the redesign of governance may be the most critical endeavor for the long-term survival of human civilization. While they are largely in dispersed and inchoate states, converging technologies and scientific approaches both underscore the importance of attending to governance issues and arrangements and also in some cases point in potentially hopeful directions. In fact, novel governance ideas are emerging from research labs and from ad hoc experiments in governance, especially those coming from virtual communities on the Internet.[1]

Converging technologies are demonstrating potential applicable insights for governance in many ways. Cognitive neuroscience is providing rich and sometimes counterintuitive data on human behavior, decision-making processes, and even the definition of the mind and personhood. These insights can be combined with emerging sciences around organizing systemic structures and bio-inspired processes

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[1] See http://www.dailykos.com/story/2012/01/24/1057803/-Democracy-Technology for a list of labs, initiatives, and experiments in "democracy technology."

to provide governance designers' ideas for new ways of ordering society at a global level. In addition, new abilities to process vast amounts of data about human behavior are making robust behavior modeling more accurate and useful. Leveraging this data and making it meaningful will be crucially important. Global modeling and modeling of complex systems will bring about new decision-making tools for businesses and governments.

Finally, while there is much overreach in the many imaging studies claiming to locate certain behaviors and traits in the brain, finding the neural correlates of critical human behaviors could help us build metacognitive extensions in order to create better outcomes. For example, understanding our brains' capacities and limitations for foresight will allow us to build governance structures (both personal and social) that account for neurological and cognitive biases that tend to favor short-term and deemphasize long-term thinking. Insights in brain communication may open new possibilities in governance (Chi and Snyder 2011).

The governance of converging technologies and the use of converging technologies to redesign governance will critically influence how we address the grand challenges we face in the "Anthropocene," an era defined by human activities and a future made by human decisions.

10.3.3 Set Grand Challenges in the Vision-Inspired Quadrant

There are two ways of thinking about Pasteur's Quadrant.[2] One way is the application of known science to achieve incremental improvements in existing technology. Another way, recommended for CKTS, is "vision-inspired grand challenges" (see Sect. 4.3.8 and Fig. 4.5), that is, the identification of big problems—ones recognized by society as vital—for which there is no current solution and that require fundamentally new science and technology to solve. Governance has a critical role to play in setting the goals for fundamental research using society's big challenges, besides the approach of curiosity-driven research.

Grand challenges in the area of governance that we will address in the next decade include the following:

- Providing governance for improving productive efficiency by combining emerging technology tools (NBIC) and human-scale platform (such as human–robot interfaces, brain-to-brain and human–machine interactions).
- Addressing global issues such as space exploration, sustainability, and a global communications system in an integrated Earth-scale approach to development. Providing CKTS solutions for a global *sustainable society* and improving overall life security on Earth. Breakthrough technical solutions for protecting and preserving natural resources will help extend the limits of sustainable development.

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[2] A concept introduced by Donald Stokes (1997) to describe scientific research that is both fundamental and "use-inspired," that takes a systems engineering approach to extending basic S&T understanding but applies it to solution of problems.

- Expanding the role of the mind (imagination, expectation, etc.) in CKTS.
- Reconstructing public healthcare based on nano-/biosensing advances and info/cognitive pattern recognition to create observational capacity for emerging diseases and an ability to anticipate public health problems emerging in large complex systems (e.g., Fisher et al. 2012). Instituting governance of theranostic medicine to integrate diagnostics, therapy, and monitoring within one system.
- Establishing anticipatory governance, including forecasting (Martin 1996). Extending governance of emerging technologies to broaden public participation. Rewriting the social contract between academic research and society; new structures are needed to handle very large problems. Adding criteria to governance that support sustainability at local and global levels.

10.3.4 Design Integrated Socio-Technical Systems

Key ideas are to create:

- Methodology and policy centers for converging technologies research and development.
- Converging knowledge and technologies platform research for emerging technologies and visionary ideas.
- Societal convergence databases and systemics (logical and mathematical paradigms to study systems from a holistic point of view; Bunge 1979; Vester 2008). This is an attempt to develop logical, mathematical, engineering and philosophical paradigms, and information research.

Human activities are increasingly embedded in complex systems that mix social with technical components interacting in complex and dynamic ways (Chap. 7). Two longstanding examples are manufacturing industries and urban transportation systems. A manufacturing enterprise not only manages the complex system that constitutes a factory assembly line but also the supply chain and financial investment systems that make manufacturing possible and the distribution systems that make it profitable. Increasingly, public transportation in urban areas is linking its components through information technology, as riders pay through smart cards (channeling money via the Internet), the location of every bus and train is provided in real time, and coordination centers are responsible for responding effectively to emergencies of many kinds. Given that some sectors of society are already organized as complex socio-technical systems, the questions arise, which others are evolving in the same direction, what innovations are required to make each different system function well, and do we need to manage all of society as single technically convergent system?

Mathematical methods, typically computer-based, can model complex systems, but they do so in a somewhat abstract manner and must work in partnership with several other approaches. Socio-technical systems tend to be assembled from components, for reason of cost, efficiency, and intelligibility, and much innovation involves improvements in a single component. For example, a fleet of busses in an urban transportation system may include a mixture of designs and over time may shift from traditional gasoline engines to natural gas. However, once a system is functioning well, it can be exceedingly difficult to improve it substantially merely by improving components. The most familiar example is a computer operating system, on which plug-and-play software programs may be designed to run; sometimes many of those programs will not run well on a substantially redesigned version of that operating system, and radical improvement of the system could require redesign of each and every piece of software. Thus, conceptual and mathematical approaches to complex systems that serve well to optimize an already-defined system must be supplemented by such other approaches as social science research, evolutionary computing that applies principles from biology to engineering design, and socio-technical laboratories for prototyping entirely novel forms of systems.

10.3.5 Address Deficits in Risk Governance for Next-Generation CKTS Products

Risk governance is an essential component for anticipatory, participatory, and adaptive CKTS. A model to address deficits in risk governance of converging technologies is the Risk Management Escalator and Stakeholder Involvement model (IRGC 2006, Figure 4) that has four progressing stages of application that require distinct risk management and public discourse processes:

For simple systems, where statistical risk analysis can be applied

1. For component-complexity–induced risk, where epistemological discourse and probabilistic risk modeling are necessary
2. For system-uncertainty–induced risk, where reflexive discourse and risk balancing are necessary
3. For ambiguity-induced risk, where participative discourse and risk trade-off analysis and deliberations are necessary

The governance of science and engineering currently involves very complex economic, legal, and management systems; it seems unlikely that the institutions developed decades ago are perfectly suited to today’s rapidly changing circumstances. It would not be wise to recommend reforms without first using rigorous methods to assess the current institutions and develop appropriate alternatives. Yet there are clear signs that problems are endemic to the current systems, as illustrated by the public controversies about climate change, healthcare, and national defense investments, all of which have substantial science and engineering components. One oversimplification that dominated past thinking was that public involvement in decisions about technological development was required only when unusual harm might be done, such as health hazards if certain potentially harmful particulate matter were released into the environment in substantial quantities. Otherwise, it was assumed that the financial investment industry and the free market would make the right decisions. Clearly, rapid scientific and technological progress is absolutely essential for the wellbeing of humanity, but a better sense seems to be needed and deliberated of which directions such progress should take.

Two approaches for the social sciences to take can be identified now, and perhaps others can be invented. First, modern methods based on traditional opinion polling and conducted online could measure the changing values of the general public to identify the goals that are important to people, and then experts in the relevant fields of science and technology can determine how to achieve those public priorities. Second, in each area of technical decision-making, ordinary citizens may select professionals, such as academics or leaders in industry, who will serve as their representatives in deliberations in the given area; in making their selections, citizens could consult online blogs by the candidate technical representatives or rely upon advice from opinion leaders in their own community whom they personally trust. The fact that we cannot specify now the exact way these challenges need to be addressed only reinforces the need for imaginative research and active experimentation.

10.3.6 Improve the Cultural Balance Between Collaboration/Harmony and Confrontation, as Informed by the Global Context and by CKTS

There are different interpersonal levels to address when considering governance and CKTS:

- Collaboration and conflict resolution among people from different countries or communities
- Maintaining harmony between country or community groups
- Promoting better interaction between scientists and the general population
- Facilitating convergence between the real and virtual worlds (Bainbridge 2010)
- Enabling better work and personal satisfaction for individuals

The contexts show the urgency and the possibilities: an increasingly crowded planet with smaller buffers between countries or communities; the increased benefits from collaboration facilitated by global information systems and science and technology resources; and the increased destructive power of new tools and technologies.

10.4 Infrastructure Needs

The main infrastructure needs for CKTS are in the following areas:

- Preparing people and tools for convergence, including in formal and informal education settings; establishing multidisciplinary physical infrastructure with measurement and manufacturing capabilities; implementing scientific results in

Table 10.4 Examples of regional and local partnerships

Partnership model	Main location	Specific
Silicon Valley (see Sect. 10.8.2 below)	California	Venture funds
Oregon Nanoscience and Microtechnologies Institute	Oregon	Technology cluster
Albany NanoTech Complex	New York	CKTS industry-government-education
Research Triangle	North Carolina	CKTS university-industry-government
Huntsville Aeronautics	Alabama	CKTS industry lead
Pharmaceutical industry in NE United States	New Jersey	CKTS industry lead
Grenoble Center	France	Nano-bio-electronics
Aachen-IMEC-Eindhoven	Germany-NL	Nano-bio-electronics
Dresden platform	Germany	Nano-bio-electronics
Tsukuba platform	Japan	University-industry-government
Samsung platform	Korea	CKTS industry lead
Nanopolis	China	CKTS industry lead

multiple areas; and advancing a creative, integrative, and innovative culture. An illustration is regional convergence, where geographically grouped partnerships and initiatives are supported. Several examples are shown in Table 10.4.
- New communication methods (Internet, various telecommunications, etc.) and social media as infrastructure for governance.
- Development of common nomenclature and informatics for CKTS, as well as neutral professional or societal "observatories" for dialogue.
- A support infrastructure for public participation.
- Investment into research on methods of convergence, creativity, and innovations in governance.

10.5 R&D Strategies

Several possibilities exist for improving CKTS governance in the global ecosystem:

- Use open-source (including social media) and incentive-based models in governance.
- Implement long-term planning with systemic and international perspectives.
- Build in flexibility in investments to adapt to technological developments.
- Harmonize regulations in high-technology areas, and institute voluntary measures for risk management when the regulations for emerging technologies are not in place.
- Adopt anticipatory, participatory, real-time technology assessment and adaptive governance of nanotechnology. The shift to new generations of CKTS products needs to focus on higher productivity and products not available before, uncertainty in risk management, and making decisions with incomplete information.

- Harmonize global R&D by standardizing principles for merit review and research integrity, sharing resources to increase the scope and global impact of scientific experimentation, exploring new options to share the research output of major scientific infrastructure projects, developing ways to guide the collection, analysis, and distribution of scientific information and "big data," and enhancing transborder mobility of researchers (Suresh 2012).

10.6 Conclusions and Priorities

Increased recognition of the dynamic interactions between scientific, technological, and societal developments associated with converging technologies points to the overall importance of governance as a critical component for maintaining national and regional competitiveness and cooperation in this area. Converging technologies are potentially transformational and therefore offer immense societal benefits but also raise social and ethical concerns. Converging technologies promise an array of innovative products, skills, and solutions, but these must be developed in socially responsive ways in order to ensure that public investments contribute to advancement of the key policy goals of economic strength, societal benefits, and national competitiveness.

These goals cannot be achieved in isolation from one another, and they require developing institutional capacities for facilitating and enhancing the interactions between science and society. Governance refers to the collective capacity for achieving socially desired benefits under complex and changing conditions. This capacity is most robust to the extent that it is distributed across multiple stakeholder groups and consists of multiple instruments, both voluntary (organic) and enforced (hierarchical). The twofold emphasis on innovation and responsibility represents a new frontier in science policy, as is evident in numerous nanotechnology and synthetic biology programs throughout the industrialized world. Leadership in converging technologies will, in large part, depend on continuing to perfect this twofold governance capacity.

The emphasis on governance has evolved over the last decade due to a variety of factors, including the continued effects of regional and global integration, the increasing rate and scope of technological change, and enhanced stakeholder abilities to discriminate credible information. Policy experimentation with different modes of program design, coordination, and evaluation, including public engagement and interdisciplinary collaboration, has generated a variety of governance models and approaches. In order to promote social responsiveness and at the same time reward scientific creativity and innovation, traditional models of knowledge production, translation, and assessment need to be integrated with each other in novel and synergistic ways.

New thinking about governance also brings its own set of challenges. Traditional institutions have a reduced role, being bypassed by social-media-enabled movements. Increased social dependence on complex technological infrastructure and evolving knowledge systems, from national security to international finance, requires input from multiple sources of intelligence that span the expert–lay divide. The convergence of disciplinary techniques, technological platforms, and governance models will also need to maintain a productive balance among competing interests—public and private, economic and ecological, individual and collective, national and international.

To avoid counterproductive regulatory and bureaucratic burdens, effective governance will need to enable researchers and policymakers to act on inputs from a broad array of stakeholders, to resist over-simplistic models of science–technology–society interactions, and to maintain flexibility in the absence of scientific certainty and normative consensus. Rather than asking scientists to supply and citizens to consume a predetermined set of technological outcomes that may fail to be productive, governance should tap individual aspirations that are the hallmark of modern democratic society, allowing these to influence the direction of evolving trajectories. Governance approaches that facilitate social learning and develop fundamental leadership skills can strengthen existing connections among scientific, entrepreneurial, and democratic competencies—connections that have shown signs of strain in recent years. In this way, convergence represents an opportunity not only to develop the technological bases, but also to build the societal foundations, for continued national competitiveness.

In order to strengthen existing linkages among national policy goals, science and innovation programs, and broad-based societal norms, governance of converging technologies will need to be guided by prominent policy criteria. In addition to supporting competitiveness technologically, economically, and strategically, these policy criteria include:

- Sustainable development—respecting the integrity of social, natural, and technological systems
- Individual privacy, especially in light of increased nanotechnology-enabled and digitally transmitted molecular diagnostics
- Human dignity and autonomy in the face of ever more powerful performance enhancements
- International coordination to avoid duplicate research targets in areas such as toxicology and to harmonize emerging regulatory frameworks

Governance arrangements should be informed by tested models that allow for a diversity of approaches, respect multiple sources of insight and innovation, and seek to strengthen rather than bypass underlying connections between scientific expertise, technological innovation, and public norms and values. Nanotechnology has helped test and evolve recent models of anticipatory and participatory governance, in which the humanities and social sciences have been brought to bear both directly and indirectly on science and innovation—from policy formulation to laboratory research—along with expanded roles for expert deliberation and citizen engagement.

For instance, Arizona State University's Center for Nanotechnology in Society has demonstrated the viability of a large-scale social scientific research program to productively engage members of the public at the national scale (Cobb 2011), synergistically integrate innovation and responsibility in the laboratory (Fisher and Mahajan 2010; Schuurbiers 2011), and develop long-term scenarios (Selin 2011) in the areas of nanotechnology, synthetic biology, and other converging technologies. The coordination of the three capacities of foresight, engagement, and integration into a research ensemble provides proof of concept for the transformative role of social science in enabling anticipatory governance of new technologies (Barben et al. 2008; Guston 2008).

In short, the innovative and responsible governance of converging technologies has emerged as a key condition for realizing societal benefits internationally and for advancing regional and national competiveness, even as it presents its own set of challenges and opportunities. As is evident from the early years of the National Nanotechnology Initiative, the United States has already provided an international leadership role in the responsible development of nanotechnology, and it is poised to take its experience into the area of converging technologies. The main priorities are to:

- Create *national centers for societal convergence* (to address knowledge-technology-society policy issues and methodologies such as convergent–divergent cycles, systems approaches, evolutionary approaches, responsible innovation, etc.) with application in areas such as research planning and evaluation, investment policies, healthcare, Earth systems, space, and other areas of national interest.
- Develop data, standards, methods, organizations, systemics, and informatics research to enable societal convergence platforms, and advance their rigorous evaluation, benefits, risks, and governance.
- Guide convergence by higher-purpose criteria such as improvement of economic productivity, human potential, and life security, including sustainable development. Both international coordination and international competitiveness are necessary components.
- Revise rules and regulations to advance individual and group creativity and innovation in convergent processes in the economy as a critical condition for competitiveness.
- Involve a broad array of publics and experts in setting priorities for large-scale CKTS initiatives.
- Adapt traditional institutions that have diminished roles as they are bypassed by social media-enabled movements. Address the opportunities and threats arising from changes in technology and governance roles.
- Support innovative and responsible governance of visionary ideas (see list in Appendix D).

10.7 R&D Impact on Society

- Proactive CKTS governance is essential for obtaining the benefits of the new technologies, limiting their negative implications, and fostering global collaboration. More specific implications are discussed in Chaps. 5, 6, 7, 8, and 9. CKTS governance affects public society at large and also international interactions.

- CKTS will support emerging technologies, general education programs, and social and even philosophical aspects of S&T development.
- EHS and ELSI are determinant factors in the success of emerging technologies and their governance.
- Responsible governance will increase creativity and innovation by offering multiple (multidisciplinary) science paths, application areas, and societal targets.

10.8 Examples of Achievements and Convergence Paradigm Shifts

10.8.1 Spaceflight: Lessons from an Earlier Convergence Platform

Contact person: *Alexander MacDonald, NASA*

The convergence of many technologies was required to make spaceflight possible, including electrical, mechanical, chemical, and computational engineering, and sciences like astronomy and physics. Thus, the history of spaceflight development is a case study in convergence—one that highlights different governance strategies. The process of spaceflight development has extended over centuries, driven largely by the intrinsic motivations of individuals to realize a specific potential future. NBIC convergence is similar in that it also is driven by a specific vision of a potential future that individuals and technical communities hope to see realized. We can divide the historical process of spaceflight development into six stages that may also be found in many other major technology developments:

- *Articulation of the Vision*. In the 1830s, three Americans independently articulated visions for a future that included human spaceflight: Edgar Allan Poe, Edward Everett Hale, and John Leonard Riddell. These visions were expressed in the form of fictional narratives that served as vehicles for the transmission of the idea of spaceflight to others. Late in the nineteenth century, individual scientists and engineers like Robert Goddard foresaw themselves personally enacting the convergence of emerging technologies to create spaceflight systems.
- *Community Formation*. As the convergence of the requisite technologies of spaceflight became possible, communities began to form around the vision as a shared goal that might be achieved through the specific technology of liquid-fuel rockets. As in the case of the American Rocket Society in the United States or the *Verein für Raumschiffahrt* (Society for Space Travel) in Germany, the first significant resources were applied to the problem, through which the physical process of technological convergence began to produce prototype systems.
- *Exchange with Other Interests*. Next, to obtain further resources in order to build operational spaceflight systems, leading groups entered into exchanges with entities that did not necessarily share their intrinsic desire for spaceflight but which saw the value of the technologies for achieving their own objectives—such

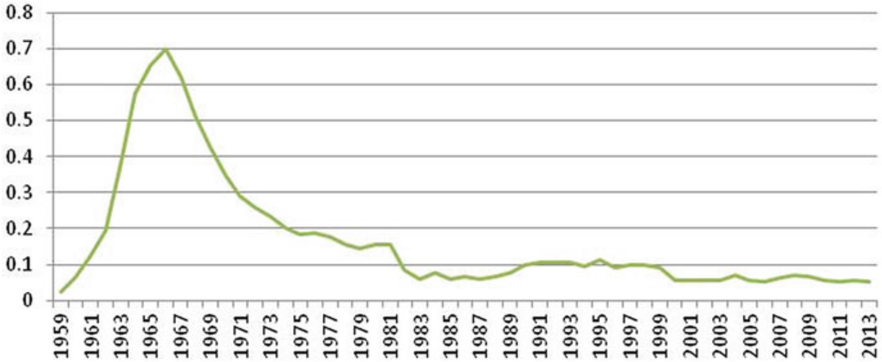

Fig. 10.5 NASA (Space) budget share of U.S. GDP 1959–2013 (Figure by M. C. Roco; data sources: http://www.whitehouse.gov/sites/default/files/omb/budget/fy2014/assets/hist09z8.xls, http://www.whitehouse.gov/sites/default/files/omb/budget/fy2014/assets/hist10z1.xls)

as the desire of German, American, and Soviet militaries for new long-range bombardment capabilities. This convergence for mutual advantage increased funding by orders of magnitude (Fig. 10.5), but also introduced the first governance strategies, which were focused on rapid development and on limiting the transfer of spaceflight technology outside the nation's military-industrial system.

- *Grand Challenge*. In 1961, President John F. Kennedy issued a grand challenge to land a man on the Moon by the end of the decade that greatly accelerated the development of spaceflight, motivated largely by geopolitical competition with the Soviet Union. This required further technological convergence, notably the integration of the digital computer into the Command Module and Lunar Module for guidance, navigation, and control.
- *Maturation*. After completion of the Apollo program, the political value of further spaceflight development waned. Nonetheless, human spaceflight retained enough political value to ensure its continuance, and the spaceflight industry entered a period of maturation where further technological convergence and development was often incremental rather than transformational.
- *Institutional Transformation*. Although there was significant cumulative progress in spaceflight systems during the maturation stage, development was nonetheless considered too slow by some members of the spaceflight community, who were motivated by an expansive vision that included near-term human settlement on other worlds. Beginning in the 1980s, a number of wealthy individuals began to invest significant private-sector capital in the development of commercial spaceflight capabilities to realize that vision.

Although mature, spaceflight technology has achieved only a small fraction of its developers' original hopes. The question faced today by spaceflight and many other mature technologies concerns whether private efforts could be sufficient to spark a renaissance of progress, or whether fundamental Government-led reformation, based on dynamic convergence across many fields of science and technology, would be required.

10.8.2 Convergence Case Study on Innovation: Silicon Valley (The Rainforest)

Contact persons: *Greg Horowitt and Victor Hwang, T2 Venture Capital (**Interview**)*

The book *The Rainforest: The Secret to Building the Next Silicon Valley* (Hwang and Horowitt 2012) proposes various tools for designing, building, and sustaining rainforests. People learn culture not from top–down instruction, but through actual practice, role modeling, peer-to-peer interaction with diverse partners, feedback mechanisms that penalize bad behavior, and making social contracts explicit. Leaders who can bridge between social networks to bind greater communities together for common action are essential to building and maintaining rainforests. Public subsidies of venture capital are ineffective when fund managers are not culturally attuned to foster symbiotic relationships between investors and investees.

The Rainforest model is more than a metaphor. Innovation ecosystems are not merely like biological systems; they are biological systems. And talent, ideas, and capital are the nutrients moving through this system. Certain social behaviors are essential to allowing the movement of those nutrients to be even freer—as they are in rainforests. It is these human networks, properly formed, that are the key to generating sustainable innovation.

10.8.3 SRC and the Semiconductor Industry as a Model for Multidimensional Convergence

Contact person: *Celia Merzbacher and Ralph Cavin, Semiconductor Research Corporation*

The Semiconductor Research Corporation (SRC) was established 30 years ago to help the U.S. semiconductor industry to better compete in the global market. The model that was created by its visionary founders called for SRC participants—at first only from industry and later also from government—to pool resources to fund basic university research that addresses the semiconductor industry's long-term technology challenges.[3] Since its inception, SRC has had three overarching objectives: (1) define relevant research directions, (2) explore potentially important new technologies, and (3) generate a pool of experienced faculty and relevantly educated students.

In the process of achieving its goals, SRC enhances and expedites convergence—the coming together of two or more distinct entities or phenomena—*in multiple dimensions*. Figure 10.6 shows the dimensions of convergence, described in more detail below, among SRC stakeholders, including member companies, State and Federal government participants, universities, and society at large. Arrows indicating the flow of information and intellectual property (IP), people, and funding illustrate

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[3] Cavin et al. (1989) provide an overview of SRC's early organization, operation, and research results.

Fig. 10.6 Schematic diagram showing the relationships among the key stakeholders in SRC research: SRC and its member companies, government partners, universities, and society at large. *Arrows* indicate the flow of information in various forms and forums, people, and funding (Courtesy of Ralph Cavin, SRC)

the strength and two-way nature of the relationship between SRC and its members and the university community. The knowledge, educated students, and IP flow to and impact not only the member companies, but also other companies and sectors of society.

The convergence dimensions of SRC's model are:

- *Convergence of discovery and innovation.* The semiconductor industry has been driven for decades to continue the trend known as Moore's Law, which states that the number of transistors per computer chip doubles roughly every 2 years. SRC works with its member companies to define fundamental research that addresses technical barriers and thereby enables continued technological progress. The portfolio of selected research is guided by industry experts, and results are extracted in near real time and delivered to the members. Many current technologies (strained silicon, high-k gate dielectrics, copper interconnects, lead-free packaging, etc.) were the subject of SRC research years in advance of their use by industry. The connection between basic research and practical applications is at the heart of SRC.

Much of the research funded by SRC addresses technology challenges described in the International Technology Roadmap for Semiconductors (http://www.itrs.net). Since the 1990s, this regularly updated document has defined challenges facing the industry in a 15-year timeframe. Many of the longest-term challenges have no known solution and require fundamental "out of the box" research. These are the areas where SRC is focused.

- *Convergence of research and education*. SRC funds leading-edge research aimed at important industry problems. Such real-world challenges attract high-quality faculty researchers, who in turn attract outstanding students. Each year, SRC supports approximately 1,500 students, who not only participate in the research as part of their education, but who also regularly interact with industry engineers and scientists. Upon graduation, most SRC students work in semiconductor-related fields in industry or academia and are able to "hit the ground running."
- *Convergence of science and engineering*. Addressing many of the challenges facing industry requires multidisciplinary and multiscale approaches. SRC supports research that ranges from materials and device science to advanced manufacturing and design tools, involving researchers from chemistry, physics, and engineering. SRC seeks ideas that address precompetitive industry challenges from the broad science and engineering university community. After research is underway, periodic research reviews bring together investigators working on related projects to share results and to obtain industry feedback. Disciplinary boundaries are unimportant in SRC decision-making.
- *Convergence of industry and academia*. Industry and academia have distinct missions and modes of operation. The mission of industry is to add value and create wealth, ultimately growing the economy; the mission of academia is education and advancing knowledge. Industry rewards profits and growth; academia rewards good research as measured by publication, recognition by peers, and ability to obtain research funding. Industry tends to operate on a short time frame and generally treats information as proprietary. Academics typically share research results openly and operate on the time scale of a graduate student's Ph.D. research project (~3 years). SRC serves as a bridge between these two worlds, working with industry to identify longer-term research problems that are suited to university research, providing academics the right to publish their results, ensuring SRC members have necessary IP rights, and providing in-person and electronic mechanisms for industry–university interaction.
- *Convergence of U.S. and international research(ers)*. Today, research expertise and excellence is distributed around the globe, and companies, including SRC members, have operations worldwide. Although restricted to U.S. universities at the outset, since 2000 SRC has accepted and funded proposals from institutions worldwide, thereby expanding the academic research enterprise focused on semiconductor research. By end of 2012, SRC had funded 86 projects at universities in 26 countries outside the United States. Researchers at universities outside the United States are integrated into the overall program, interacting and collaborating with other SRC-funded academics and with member company technologists.

- *Convergence of students and mentors*. A critical element—and benefit—of SRC research is the enhanced experience of students. At the task or project level, at least one industry expert serves as a liaison, guiding the research in near real time and mentoring the students. Industry mentors help students appreciate the industry perspective and needs motivating their research and open their eyes to careers in industry, arranging for internships and other opportunities. Students interact with many more industry representatives at research reviews and an annual technical conference that includes students from across all SRC research programs.

SRC Outcomes (Divergence of Results)

The impact and outcomes of SRC after 30 years are both quantitative and qualitative. Since 1982, SRC has directed more than $1.4 billion in university research. In addition, SRC staff and industry members have participated in proposal reviews, workshops, and other activities that influence how Federal funds are spent. Through its investments, SRC has built a substantial network of university researchers focused on semiconductor-related research. When SRC was created in 1982, fewer than 100 academic researchers were doing research relevant to the semiconductor industry. Today, SRC supports approximately 2,000 faculty and student researchers annually. To date, a total of more than 9,000 graduate students and 2,000 faculty members have been supported at over 200 universities worldwide. A number of faculty researchers have received SRC funding for many years, in some cases going back to their own graduate student research. The numerous relationships between industry technologists and faculty researchers are a less readily quantified yet extremely valuable asset, providing industry with access to leading experts and providing academia with access to real world experience, and on occasion, to samples and facilities.

Of high value to industry is the pipeline of relevantly educated scientists and engineers. Upon graduation, approximately half of SRC students take a first position at a member company. About 30 % go to other semiconductor-related industry positions, and 15 % go to academia or government labs.

SRC-funded research also produces numerous technical publications in peer-reviewed journals. A measure of the impact of such papers is the number of citations by others, and a measure of potential commercial value is the fraction of citations from papers by authors from industry. At least 210 papers reporting SRC-funded research have received more than 100 citations, and some have surpassed 1,000 citations. Of those receiving more than 100 citations, almost two thirds received at least 15 % of the citations from industry-authored papers.

Another measure of research output is patents. SRC's IP policy is primarily defensive, allowing universities to own the rights to any resulting intellectual property, including patents, while retaining a nonexclusive, paid-up, royalty-free license for all members. This policy insures members have the freedom to operate. When an invention is made, SRC, in consultation with the members, decides whether a patent application should be filed, and if so, it pays the associated costs. By 2012, SRC research has resulted in nearly 400 patents.

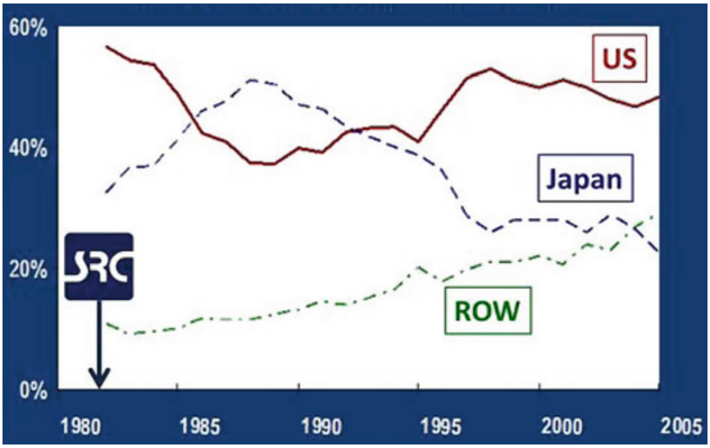

Fig. 10.7 Global semiconductor market share held by companies headquartered in the United States, Japan, and the rest of the world (ROW) in 1980–2005 (Courtesy of Semiconductor Industry Association)

Despite the open publication policy and the IP rights provided by SRC contracts, at least 25 startup companies have roots in SRC research performed at universities across the country. The companies provide products and services that range from software for chip design to specialized metrology tools. Several have been acquired, in some cases by an SRC member company. These new businesses are built upon innovative solutions and create both value and jobs.

The direct economic impact of SRC on the semiconductor industry is difficult to quantify. Despite notoriously short product lifecycles, as in other sectors it is typically on the order of 12 years from the time a new material or technology is discovered (i.e., the basic research phase) to when it is incorporated in a commercial semiconductor product or process. Even SRC research shows a similar research-to-product transition time (Herr and Zhirnov 2004). SRC was established in part to help address the decline in the world semiconductor market share held by U.S. companies. Within 10 years after the creation of SRC, the trend reversed, and since the late 1990s the U.S. semiconductor industry has held about 50 % of the global market (Fig. 10.7). During this time, SRC has continuously produced research results and a relevantly educated workforce to which SRC members—which until 2000 were limited to U.S. companies—have enhanced access.

SRC Impact Beyond the Semiconductor Industry

Although established by and for the semiconductor industry, SRC has had broader impact. SRC produces research results that are disseminated broadly in scientific and technical publications and presentations at conferences and workshops. It provides top-notch graduates who follow careers not only in the semiconductor industry, but also in other sectors and in academia and government. Today, SRC alumni are science and engineering leaders at top universities and in businesses ranging from large technology companies to startups.

To the extent that SRC has helped the semiconductor industry to continue along the trend defined by Moore's Law, it has contributed to the broad impact of the industry across the economic landscape. Semiconductors are at the heart of information technology, making the Internet and the "knowledge-based economy" possible. Semiconductors provide the "intelligence" in devices and systems used in medicine, energy generation and use, and security. Moreover, the use of semiconductors in a host of products and services has enabled increased productivity and growth in virtually every sector. Based on analysis of data collected by the Department of Commerce from 1960 to 2007, semiconductors accounted for nearly 30 % of economic innovation overall and correlated with 37 % growth in labor productivity in the Communications Equipment industry, 25 % growth in the Other Electronic Products sector, and 14 % growth in Educational Services (Samuels 2012).

Finally, the success of SRC and its various programs has been evaluated and held up as an example for public–private partnership and research management for other sectors to consider. The President's Council of Advisors on Science and Technology commended in particular the Nanoelectronics Research Initiative, a subsidiary of SRC, in its 2010 review of the National Nanotechnology Initiative (PCAST 2010). More recently, a Harvard Kennedy School report on energy innovation concludes that the strong connection between industry and academia created and managed by SRC contributes to technology relevance and private sector uptake (Diaz Anadon et al. 2011). These reports acknowledge the accomplishments of SRC and suggest that a similar approach could improve the efficiency and effectiveness of other (government-funded) research programs.

Where Is Convergence Taking the Semiconductor Industry?

In the near term, convergence is creating opportunities for the semiconductor industry. Computing power that is smaller, faster, and cheaper makes possible new products and new capabilities. Examples include medical diagnostic tools that allow physicians to see inside the body and automobile systems that detect when an accident is imminent and take action. Such advanced electronics require much greater convergence during the design process between the semiconductor and biomedical or automotive engineers. As Moore's Law and the ability to increase performance by scaling to smaller dimensions reaches physical limits, SRC seeks possible new approaches for advancing the power and utility of what today is referred to as "semiconductor technology" by supporting research to explore new materials and physics to store and transmit information.

In the longer term, convergence among scientific and engineering disciplines points the way to the future of the semiconductor industry. Many have noted the efficiency of biological systems, comparing the human brain that consumes 20 W

Table 10.5 Share of total global R&D spending, by country or region

	2011 (%)	2012 (%)	2013 estimated (%)	Difference 2012 vs. 2011 (%)
Americas	34.8	34.3	33.8	–0.5
U.S.	29.6	29.0	28.3	–0.6
Asia	34.9	36.0	37.1	+1.1
Japan	11.2	11.1	10.8	–0.1
China	12.7	13.71	14.7	+1.01
India	2.8	2.8	3.0	+0.
Europe	24.8	24.5		–0.3
Rest of World	5.7	5.7	5.7	+0.0

and a high-performance computer that requires nearly 10 MW of power. Of course humans and computers are optimized for different types of tasks, e.g., facial recognition vs. numerical computation. But can computation take advantage of some of Nature's strategies for signal processing and communication, as well as for extracting energy from the environment? Advances at the convergence of biology, electronics, and information technology offer prospects for novel cyber-physical systems that connect people with each other, the environment, and information in order to provide on a global scale everything from improved security, energy, and transportation systems to accessible and affordable healthcare.

Conclusion

The semiconductor industry provides tools that grow the economy. It has continued to improve those tools over time, in part by its investment in research for the future; the U.S. semiconductor industry invests on average 17 % of sales in research annually. A component of that investment is through SRC, which serves as the most forward-looking arm of industry research. SRC plays a key role in bringing industry together to define, support, and guide basic precompetitive university research, in coordinating multidisciplinary academic researchers, and in delivering results and outstanding graduates to its members. In the process, SRC has helped the semiconductor industry to continue advancing the power of computers and intelligent systems. With convergence among disciplines and along the innovation pathway becoming increasingly crucial to economic and societal progress, consortia like SRC can play a vital role in bridging boundaries in multiple dimensions.

10.8.4 Global Trends in R&D Investment

Contact person: *Martin Grueber, Battelle*

Table 10.5 shows the percentage contributions of various countries and regions to the annual global R&D spending, and their respective changes between 2011 and 2012 (based on Battelle 2012; Grueber and Studt 2012).

A separate study shows that of all students who studied abroad in 2000, 23 % chose to study in the United States. By 2009, this had declined to 18 % (OECD 2011).

These trends are expected to be significantly affected by the adoption of emerging technologies and convergence (CKTS) in the respective economies.

10.8.5 Examples of NSF-Funded Research Projects on NBIC (Converging Technologies) 2001–2012

Contact persons: *M. C. Roco, National Science Foundation*

Table 10.6 illustrates various modes of support of NBIC awards at the U.S. National Science Foundation.

Since 2010, the NBIC awards with at least two components per award have represented about 5 % of total NSF awards.

10.8.6 Public Participation and Innovation Ecosystems for Convergence

Contact person: *David M. Berube, North Carolina State University*

Public participation in science and technology policy decision-making has been asserted by many contemporary critics to be a tenet of public sphere theory. Contemporary participation exercises come in many forms: planned and unplanned. Planned exercises run from scheduled elections, which might include visionary technological issues to consensus conferences and citizen juries. Unplanned exercises are instantaneous discussions and dialogues at work stations or in church basements. And somewhere in the middle are consumption patterns (we buy what we want and exercise our choices in that fashion). Such exercises can be inorganic or organic (Gehrke 2008; Breau and Brook 2007). Inorganic exercises involve formal meetings for which participants are recruited and often paid. Organic exercises involve reaching out to the public, where they already meet, to join in on their agenda. An interesting variant of this is the science café, which mixes both—participants gather to listen, discuss, and argue in an untraditional venue such as a restaurant or a pub. While inorganic participation has a clear and often rigid agenda, the organic form is fluid, accommodating, and “messy”.

The convergence of knowledge and technology could have profound impacts on who we become and how we fit in the general order of nature and the cosmos. The impact sets include a range of effects, such as developments in computation and improvements in health and well-being. On a different scale, the sets might also include off-planet development, significant life prolongation, and transhumanist evolution. The first set is less problematic for the public, whereas the second set can conflict with beliefs and attitudes, hence, confirmation conflicts (see above). This potential for substantive impacts of a defining order demands participation by

Table 10.6 Examples of awards made by NSF since 2001

Year	Award number	Title	Award	Principal investigator	Institution
2006	550169	Developing Ontological Schema Training Methods to Help Students Develop Scientifically Accurate Mental Models of Engineering Concepts	$755,163	Miller, Ronald	Colorado School of Mines
2010	1002410	Nanotechnology from Basic Science to Emerging Applications: Institute for Functional Nanomaterials (IFN)	$20,000,000	Weiner, Brad	University of Puerto Rico
2012	1160483	NSF Nanosystems Engineering Research Center for Advanced Self-Powered Systems of Integrated Sensors and Technologies (ASSIST)	$18,499,997	Misra, Veena	North Carolina State University
2012	1241701	Center for NanoBiotechnology Research	$4,995,710	Singh, Shree	Alabama State University
2004	335765	NNIN: National Nanotechnology Infrastructure Network	$152,762,150	Tiwari, Sandip	Cornell University
2010	936384	Operation of the Cornell High Energy Synchrotron Source (CHESS)	$77,586,038	Gruner, Sol	Cornell University
2003	310717	Engineering Research Center for Extreme Ultraviolet Science and Technology	$40,726,563	Rocca, Jorge	Colorado State University
2006	618647	Collaborative Research: Institutionalizing a Reform Curriculum in Large Universities	$599,961	Haugan, Mark	Purdue University
2001	122419	ITR/SY: Center for Bits and Atoms	$25,326,990	Gershenfeld, Neil	Massachusetts Inst. of Technology
2010	939514	Center for Energy Efficient Electronics Science (Center for E3S)	$25,000,000	Yablonovitch, Eli	University of California–Berkeley
2011	1125565	Institute for Quantum Information and Matter (IQIM)	$11,400,000	Kimble, H.	California Institute of Technology
2004	0425780	NSEC Nano-bio	$11,426,000	Bonnell, Dawn	University of Pennsylvania

as many stakeholders as possible. Members of the public will need to reexamine their sensibilities, if not their beliefs and attitudes sets, to accommodate life and definitional changes. If the investments in time, psyche, and funding toward technological convergence are to become manifest, public support, or at least acquiescence, is needed, especially if products of convergence end up as market goods that need to be consumed.

The assumption that the convergence of knowledge and technology is affected by societal/public needs is partially true. There are calls for unprecedented solutions to especially challenging or sticky (von Hippel 1994) problems, such as climate change (Nisbet 2009) and infrastructure shortfalls (Spence 2011). When a social problem surfaces that cannot be resolved by nature or humanity's plodding evolution of solutions, there are demands for "new" ways to resolve issues, and especially those steeped in uncertainty and speculation, such as synthetic biology (Armstrong 2012; Keck Futures Initiative 2009).

While it might be true that the causes of some of society's most vexing problems may be society itself, one reaches a point where that argument does not provide solace. How we got where we are is less important than how we get out of the predicaments we may have created. We must accept responsibility for these problems we created and try to come together to find ways to solve them. While technological fixes are not necessarily the best answer to all technological problems (Tenner 1997), they do tend to be appropriate for many. In an effort to resolve societal conundrums, we attempt to merge what we know and what we can do, in turn spurring technological evolution. While we may produce another set of problems as well as solutions, the costs of inaction and retrogression are simply too great. Thus, if the best option at hand is to rise to the occasion and move forward, human society remains an important partner in the process, and its members deserve to know what is at stake and to help to choose the directions we take (Sarewitz and Nelson 2008).

On the other hand, critics contend that convergence is the product of a few stakeholders attempting to control resources and wealth to forward a more self-serving agenda, rule by mega-elites (ETC Group 2003). It is true that those who can afford to move ahead, shedding externalities like financial resources that might impede their momentum because they often can afford to aggrandize both power and wealth. Whether this case can withstand scrutiny or not (Baumol 1986; De Long 1988; Baumol and Wolff 1988), it may be prudent to find as many ways as we can to enable the whole set of stakeholders to participate in understanding as well as advancing a public convergence agenda that benefits as many stakeholders as possible, as much as possible, and as equally as possible (ETAG 2005). While irregularities and inconsistencies may still erupt, participation may offer the best solution to minimizing public losses and maximizing public gains.

Understandably, the public will demand that immediate problems are not forgotten as we advance an agenda involving long-term problems, and this is an important cost to development of all sorts. Participating publics want solutions to immediate issues, like housing, employment, and other basic needs. While this mindset does not preclude longer-term planning, it limits it. Anyone perpetrating in a long-term convergent technological set of inquiry as well as policies will need to deal with this reality. Members of the public are reluctant to sacrifice their present for someone else's contrivance of their future. As such, public participation activities involving convergence are prickly.

Consider the convergence platform associated with computation and digital media. We have discovered that the personal computer in every home has risen to the necessity level of home heating and cooling systems. This phenomenon is evident throughout much of the West and extends to the developed cultures of the East and the South as well. While we hear voices calling out to warn us of its effects in defining who we are (Carr 2010) and bemoan the birth of a "search engine society" (Burgess and Green 2009; Halavais 2008; Hassan 2008), except for students in digital critical theory and some technology cognoscenti, these voices are seldom heard by the public. The public seems more or less to have acquiesced. Whether they will respond similarly to convergence is unclear.

Finally, and importantly, convergence should contribute new platforms for participation (Mossberger et al. 2007; West 2011). Innovation networks characterize much of the literature on technological convergence. They are overlapping and intersecting visions of how knowledge and its products iteratively interact (Burke 2011). These ecosystems have nodes dedicated to financial inputs, sustainability values, technological breakthroughs, and educational values, among others. These are authentic axiologies (Rescher 2005), or value systems. The business world has learned how to tap the public via tools like the Internet to help them decide what products the public needs and wants as well as how to improve or even remove products that are in their inventory and on the market. The feedback loops work best when the range of participation is very broad. Convergence affects a plethora of human beliefs, attitudes, and values. How public participation interacts with it can be described as an innovation ecosystem (Adner 2006; Anthony et al. 2006).

In general, innovation is driven by a battery of motivations, competing innovators, and a general awareness of separating rediscoveries from truly innovative acts. In turn, innovation enters the overall agenda of many different stakeholders who comment and interact by specifying how the innovative act interacts with their needs and wants. Responding to stakeholders' input, innovators assess, adapt, and adjust the innovative processes and products to improve their interactions with as many stakeholders as practical. Next, stakeholders reassess and reevaluate the processes and products to determine exigency (importance) and salience (relevance) (Bitzer 1968). In response, innovators reassess, readapt, and readjust the innovation before it becomes marketable. Further developments associated with the innovative act, process, and product renter the cycle, which is iterative (Fig. 10.8).

Innovative ecosystems cannot be ignored, and those who ignore them do so at their own peril. "In a world where the rate of initiative and change continues to accelerate, where expertise and ideas are more distributed than ever, enterprises that do not feel in their day-to-day activities the expansion of their ecosystem are probably falling behind on innovation and growth opportunities" (Cramer 2011). Furthermore, "an innovation ecosystem could be envisaged as a system which supports the birth and growth of innovative activities in a self-sustaining manner" (Dasgupta 2010). Simply put, given investments, the system functions as

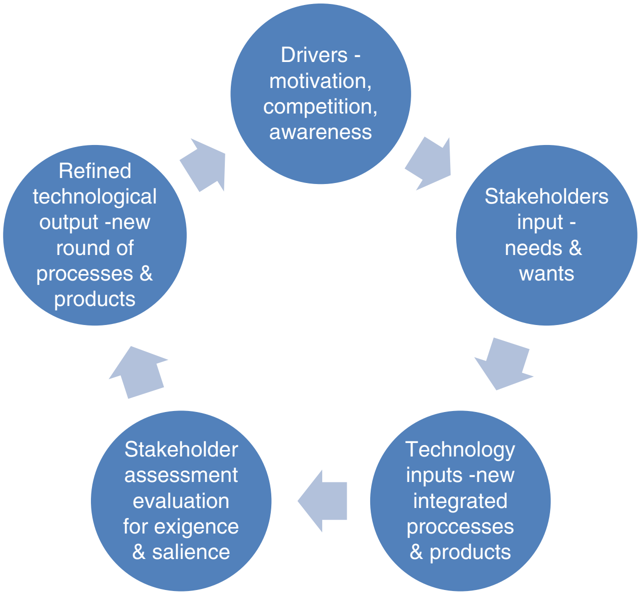

Fig. 10.8 Innovation ecosystem and stakeholders (Courtesy of D. M. Berube)

a working economy to perpetuate itself. Investments made today should percolate through the system, magnifying subsequent inputs and outputs. Consequently, participation in innovation ecosystems becomes essential to prevent the self-perpetuating nature of the ecosystem from sidelining much of the public from its benefits (Collier 2007).

10.8.7 Global Risk Governance Through Managing Resources at Multiple Scales

Contact person: *Marietta L. Baba, Michigan State University*

A new trend in risk governance is incorporating polycentric global commons. The risk governance framework for CKTS could be enhanced by incorporating the work of Nobel Laureate Elinor Ostrom on economic governance of the commons. She shows that groups of users can develop and implement mechanisms (e.g., rules) for managing common economic resources to "sustain tolerable outcomes" (Ostrom 2009). This work has been extended from the scale of the "local" to the "global" through the concept of "polycentric governance" (that is, managing resources at multiple scales; Ostrom 2010). Ostrom's design principles for governance of the commons have been elaborated to include emerging technologies (Stern 2011; nanotechnology is specifically named).

Different dimensions of the convergence that consider interactions at multiple scales must be included for this purpose. Cognitive science is a successful academic program that is broadly interdisciplinary, linking several different natural science and social science disciplines, driven by the need for the knowledge from those disciplines and making links in society. This field recognizes that cognition is a process that takes place not only in the (individual) brain but also between and amongst brains and minds; that is, cognition develops within and through social interactions between people—cognition is in part social; e.g., cultural schemas are shared (Quinn 2005). This is why CKTS must incorporate social science and humanities, because humans are fundamentally social beings.

10.8.8 Convergence Aspects of the EU Horizon 2020 Vision

Contact person: *Christos Tokamanis, European Commission*

The CKTS workshops findings and report has commonalities with the European Commission's proposal for a multi-annual 2014–2020 framework programme of research and innovation activities called "Horizon 2020" (H2020). The points of "convergence" between this CKTS study and the H2020 proposal (April 2013) can seen in the brief description below.

The priorities of H2020 are—in line with the Europe 2020 strategy and the Flagship Innovation Union—short-to-medium-term oriented, and they focus on growth, competitiveness, solutions for society's challenges, and employment. H2020 has three pillars: generator of knowledge (excellent science), technology developer (industrial leadership), and preparing the building blocks for answering the societal challenges. These pillars may correspond to the creative phase, integration phase, and application divergence phase in the convergence–divergence model (Fig. 4.1 in Chap. 4).

A. ***The Pillar "Excellent Science"***

Its structure is made up of generating knowledge bottom-up (European Research Council, ERC) and top-down (Frontier Emerging Technologies, FET), as well as infrastructure and training.

The core of the generation of fundamentally new knowledge and technologies in H2020 is concentrated in the pillar "Excellent Science" (about 33 % of the H2020 budget[4]) which focuses on fundamental research, infrastructures, and the development of scientific talent. The ERC does not foresee any thematic orientation. The proposed FET scheme aims at fundamental research with the potential for long-term applications (it foresees a funding of about three billion Euros for 7 years). It comprises three main parts with different kinds of focus: (1) FET Open, very broad, with potential for break-through results; (2) FET

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[4] The budget data are taken from the COM-Proposal for HORIZON 2020 (COM(2011)811), 30.11.2011, and can be strongly modified due to readjustment of the budget due to negotiations of MFF 2014–2020.

Proactive, which is thematically more focused on the goals for long-term applications in the topical field that are not yet ready for inclusion in industry research roadmaps; and (3) recent FET Flagships, preparing the ground by long-term, large-scale research on high-potential topics

B. ***The Pillar "Industrial Leadership"***

The pillar "Industrial Leadership" (24 % of the proposed budget) means leadership in enabling and industrial technologies, the major component of which is key enabling technologies (KETs): nanotechnology, nanoelectronics, photonics, biotechnology, materials, and (cross-cutting) manufacturing. KETs (about € 5.8 billion in 7 years) aim at improving the connection between research and applications, with a strong accent on application and demonstration. Strong private sector involvement, including public–private partnerships, in such activities will be a prerequisite. The demand-oriented activities "Access to Risk Finance" and "Innovation in SMEs" complement the R&D&I [research, development, and innovation] activities and do not include long-term or fundamental research. One focus of this pillar is "cross-cutting key enabling technologies, which will enhance product competitiveness and impact and stimulate growth and jobs as well as provide new opportunities to tackle societal challenges" leading to a "joint work programme for cross-cutting KETs activities." In the cross-cutting activities, however, impetus can be expected for topics in fundamental research.

As examples of convergence, the ICT [information and communication technologies] section of this pillar foresees that "a number of activity lines will target ICT industrial and technological leadership challenges *along the whole value chain* and cover generic ICT research and innovation agendas." The biotechnology section states that, "The objective is to lay the foundations for the European industry to stay at the front line of innovation, *also in the medium and long term. It encompasses the development of emerging technology areas* such as synthetic biology, bioinformatics and systems biology, as well as exploiting the convergence with other enabling technologies such as nanotechnology (e.g., bionanotechnology) and ICT (e.g., bioelectronics), and engineering technology." In order to assure the inflow of fresh ideas with a breakthrough potential in the area of key technologies, however, a well-conceived link is established in both directions, i.e., the knowledge and information flow from Excellent Science to KET and vice versa would be beneficial, particularly in the medium-to-long term.

C. ***The Pillar "Societal Challenges"***

The third pillar, "Societal Challenges" (43 % of the budget), is strongly oriented towards societal challenges. The broad lines of the activities and specific objectives are:

- Improving lifelong health and well-being
- Securing sufficient supplies of safe and high-quality food and other bio-based products, by developing productive and resource-efficient primary production systems, fostering related ecosystem services, alongside competitive and low-carbon supply chains

- Making the transition to a reliable, sustainable, and competitive energy system in the face of increasing resource scarcity, increasing energy needs, and climate change
- Achieving a European transport system that is resource-efficient, environmentally friendly, safe, and seamless for the benefit of citizens, the economy, and society
- Achieving a resource-efficient and climate-change-resilient economy and a sustainable supply of raw materials in order to meet the needs of a growing global population within the sustainable limits of the planet's natural resources
- Fostering inclusive, innovative, and secure European societies in a context of unprecedented transformations and growing global interdependencies

10.8.9 Innovative R&D System for Converging Technologies (Korea)

Contact: *Heyoung Yang, Korea Institute of S&T Evaluation and Planning (KISTEP), Korea*

The proposed organization for governance of converging technologies has been informed by the NBIC studies since 2001 and the 2012 NBIC2 workshop in Korea.

In recent years, the goals of science and technology innovation policy include not only contributing to economic development but also satisfying general societal needs. A recent study concerning future society shows that closely related keyword clusters can be used to draw an "issue-keyword network" (Fig. 10.9).[5] These clusters designate future society issues and needs and can be used to trigger the creation of new user-friendly converging systems, assembling a variety of technologies at the beginning stages.

These technologies are dynamically converging to the new technology and a system with shared goals, by breaking boundaries between them. In addition, the characteristics of converging technologies might differ between nations since their societies' issues and needs might vary depending on their national situations. At the same time, the time dependency of an issue keyword network makes us deduce the dynamic characteristics of converging technologies due to changes over time in the issues and needs that are identified.[6]

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[5] Based on keywords from trend analysis, the frequencies for co-word pairs between keywords appearing in Google documents (2007–2009) have been counted. The number of counts designates the strength of connectivity between the keywords, and this can be shown as in Fig. 10.10 utilizing the network drawing program, "Netminer".

[6] As compared with the results of the same analysis for Google documents during 2004–2006, megatrend which is related to the formation of the clusters does not change, but the degree of the connectivity between the issues does change, meaning that there are emerging hot issues in recent years such as climate change–health, climate change–global governance and social network–healthcare connections.

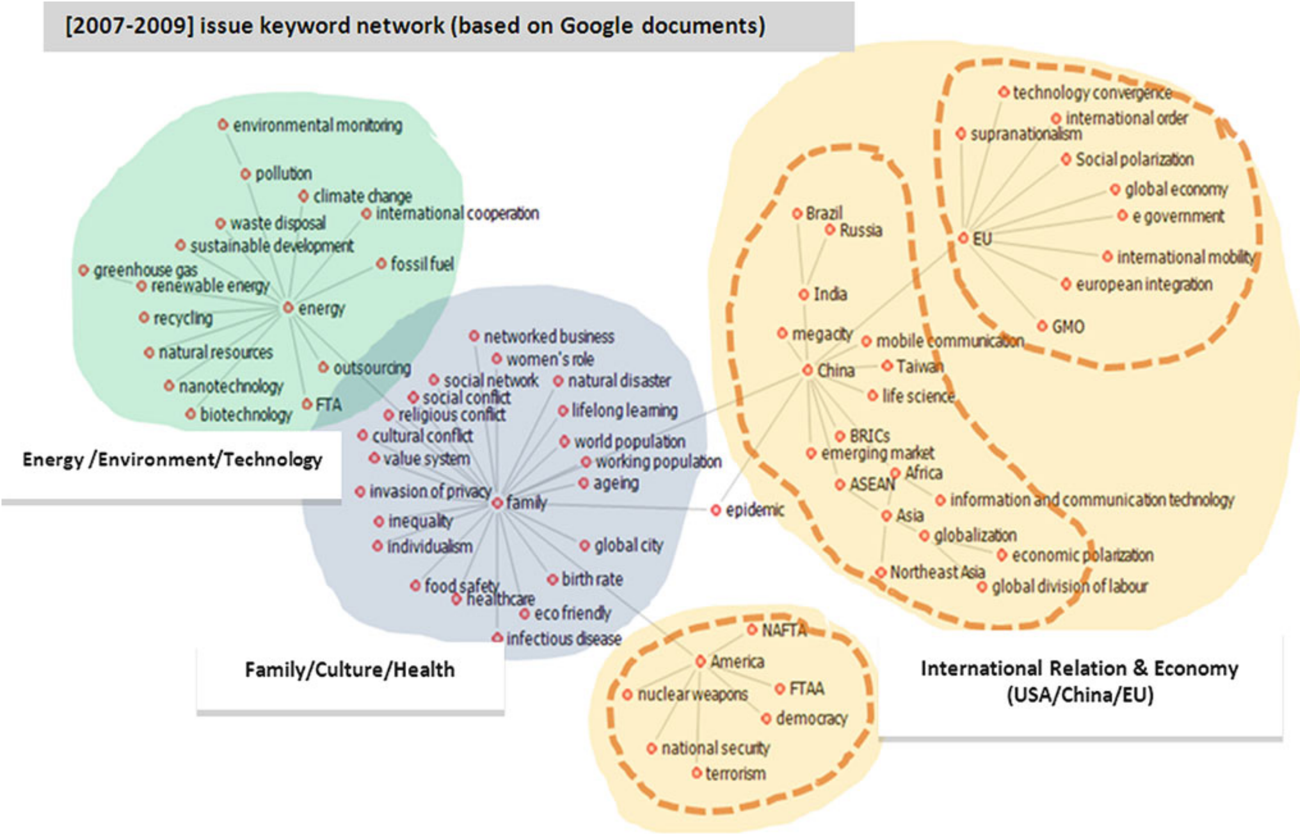
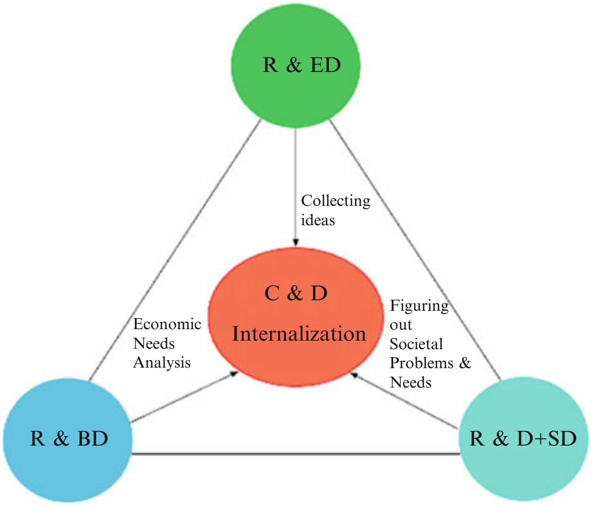


Fig. 10.9 Issues and needs for future society (Yang 2012; Courtesy of H. Yang, KISTEP)

Fig. 10.10 Innovative "organization-friendly" open-cooperation R&D system for converging technologies (Based on Jeon and Jeong 2010, 23, ©ETRI; used by permission)



In this context, there must be a discussion on how to achieve an innovative R&D system that considers the characteristics and the trends of convergence. Especially, to attain policy goals such as economic development, improved quality of life, and sustainable development, a holistic innovation policy and integrated approach, such as multisectional policy plans, should be established that untangles the complicated and interrelated socio-economic needs and problems.

From the viewpoint of organizational theory, the collaboration system between government ministries and R&D institutes and organization units should be built to facilitate spontaneous and intimate cooperation, breaking up "sectionalism." Therefore, the top priority for R&D investment is to build a research collaboration program. Furthermore, the flexibility of research organizations has to be secured, which will enhance the mobility of human resources and creative environments.

Current regulations and laws related to converging technology need to be gradually reformed. The introduction of an "open-innovation R&D system" such as an organization-friendly R&D eco-system should be considered (Fig. 10.10). This ecosystem should integrate the R&ED (research and education development) system to emphasize collecting innovative and original ideas, the R&BD (research & business development) system to focus on the pragmatic business needs for commercialization, and the R&SD (research and solution development) system to address societal needs and problem-solving. Here, the main concern is how well we can construct a collaboration system based on a "connect and development" approach between creative human resources. Inside and outside networks and internalization of new outsourcing knowledge into the organization should be the main focus in this system.

In Korea, a bill for enhancing the competitiveness of converging technologies and facilitating commercialization was proposed to become law in 2012 after passage by the congress. The "Convergence Research Policy Development Centre

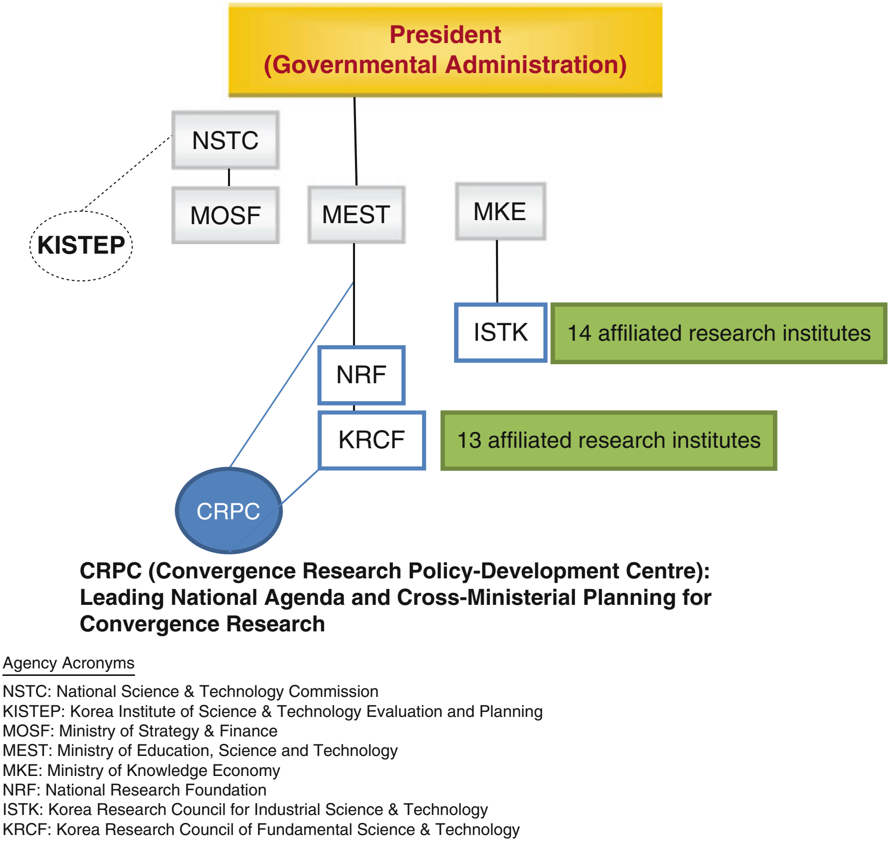


Fig. 10.11 Science and technology governance structure/hierarchy in S. Korea (Courtesy of H. Yang) (Agency Acronyms: *NSTC* National Science & Technology Commission, *KISTEP* Korea Institute of Science & Technology Evaluation and Planning, *MOSF* Ministry of Strategy & Finance, *MEST* Ministry of Education, Science and Technology, *MKE* Ministry of Knowledge Economy, *NRF* National Research Foundation, *ISTK* Korea Research Council for Industrial Science & Technology, *KRCF* Korea Research Council of Fundamental Science & Technology)

(CRPC[7])" (Fig. 10.11) has been set up very recently to implement this law for building an innovative R&D system. Centre staff has started to develop a national agenda and cross-ministerial planning of long-term convergence research for the coming decades with the support of the Ministry of Education, Science, and Technology (MEST) and Korea's National Research Foundation.

Simultaneously, several representative convergence research programs with their own creative R&D systems have been launched, seemingly considered as policy experiments. The first one is the interministry program called "Nano-Based-Convergence

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[7] This is a tentative name for the organization, provided by the author, since the exact English name for the organization had been not decided at the time this description was written.

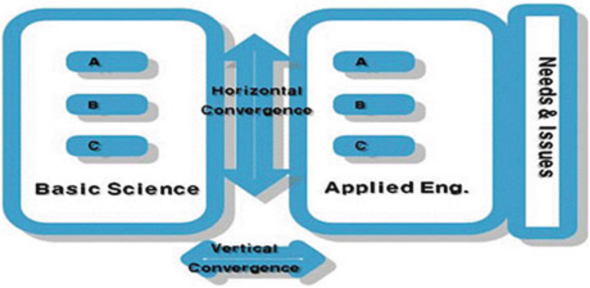

Fig. 10.12 Horizontal vs. vertical convergence in Korea's "Cutting-Edge Convergence Research Program" (Courtesy of H. Yang)

2020," sponsored by the Ministry of Knowledge and Economy and MEST. From the view of "breaking up sectionalism", this program pursues the synergy effects between two ministries and maximizing R&D efficiency by translational research, connecting basic R&D performance and ideas to business development.

The other program is the "Cutting-Edge Convergence Research Program", which emphasizes inter-disciplinarity with multi-organizational cooperation. The program collects ideas from researchers, and at the same time, planning managers conduct tests for compatibility with national R&D strategy and relevancy to societal needs through consultations with expert groups. This program pursues a "high-risk, high-return" strategy and therefore embraces the "sincere" research failure, thus supporting a creative R&D environment. The main differences between these two programs are the types of convergence characteristics, vertical or horizontal, they exhibit (Fig. 10.12).

The concept, "vertical convergence," which is well-explained for converging phenomena between basic science and applied engineering areas for specific societal needs, bridges the R&D stages in different phases. "Horizontal convergence" is a phenomena explaining converging activity within similar R&D phases, mainly creating new academic areas or ideas that can be applicable in the future.

10.8.10 Contribution of Knowledge and Technology to Sustainable Development in Emerging Economies

Contact person: *Richard Appelbaum, University of California, Santa Barbara*

The potential contribution of knowledge and technology to sustainable development in emerging economies is substantial. One recent study (Singer et al. 2005; Salamanca-Buentello et al. 2003) consulted a panel of 63 experts, 60 of whom were from developing countries, to rank the ten nanotechnology applications they felt would be of greatest benefit to developing countries over the next decade. In order of ranking (from top to bottom), these were (1) energy storage, production, and conversion; (2) agricultural productivity enhancement; (3) water treatment and remediation; (4) disease diagnosis and screening; (5) drug delivery systems;

(6) food processing and storage; (7) air pollution, prevention, and remediation; (8) construction; (9) health monitoring; and (10) vector and pest detection. Another study (Bürgi and Pradeep 2006, 648) concludes that nanotechnology "has the potential to become the flagship of the industrial production methods of the new millennium in developed as well as in the developing world."

Parker and Appelbaum (2012a, b) have identified four areas where nanotechnology and other emerging technologies (particularly at the intersection of biology and nanotechnology) have the potential to achieve breakthroughs that would improve the lives of many people in the Global South:

- *Energy/Environment*: Potential applications include more efficient appliances, solid-state lighting, enhanced energy storage with lithium ion batteries, and nanotechnology-enabled solar panels; biofuels (such as sugar cane in Brazil; Brito Cruz 2012); and potentially, solar cells.[8]
- *Water*: Potential applications include cheaper and faster diagnosis and removal of contaminants, disinfection or desalination of water through nanoporous membranes, and coatings that releases chlorine or other known disinfectants over extended periods of time.[9]
- *Food Security*: Potential applications include nanotechnology-enabled sensors (capable of detecting plant and crop disease, measuring pest and fertilizer levels, and ensuring food safety), nanotechnology-enhanced delivery of pesticide control, enhanced nutrition bioavailability, nanotechnology-enabled increased animal fertility and reproduction rates, greater protection against food-borne illness, and early detection of pathogens and disease.[10]
- *Health*: Potential applications include peptides for biopharmaceuticals, targeted and controlled drug delivery systems, labs-on-a-chip with sensors that contain thousands of nanowires able to detect proteins and biomarkers at the site of tumors, and gold nanoshells for dual imaging and cancer therapies.[11]

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[8] First-generation single-crystalline silicon solar cells operate at 10–15 % conversion efficiency; cadmium telluride (CdTe) photovoltaics may reach 20 % efficiency; multijunction, thin-layer films promise 40 % efficiencies; quantum-dot structures hold high promise, with efficiencies approaching theoretical limits (Osman 2012, 23).

[9] Chinese engineers are developing a variety of nanoscale approaches to filtration that, if successful, will remove virtually all water and soil contaminants, whether they are bacterial in origin stemming from organic wastes, or industrial effluences such as toxic metals (Wang and Huang 2012). Osman (2012, 24) notes that "novel polymeric materials and nanofibrous media may enable high flux, low pressure membranes, thus reducing energy demand." (See also Hillie and Hlophe 2012, for examples from other developing countries.)

[10] "Nanotechnology is fast emerging as the new platform for the next wave of development and transformation of agri-food systems… projected to have the potential to provide foundation for large emerging agriculture centered economies like India" (Sastry et al. 2009, 91; see also Rogers and Zader 2012).

[11] Chinese scientists in particular are making advances in the areas of disease diagnosis and targeted drug delivery (Wang and Huang 2012).

How a Focus on Sustainable Development Affects Other Areas of Knowledge, Technology, and Global Outcomes

Increased cross-border collaboration—much of it across the advanced/developing country divide—furthers the ability of nanotechnology and other emerging technologies to play a key role in sustainable development (Wagner 2008; Wagner et al. 2001). This increase will ideally produce a truly global "open-source" approach to the development and regulation of nanotechnology and other emerging technologies, one that involves transparent and readily adaptable systems of governance and that speeds the advance of nanotechnology in support of more sustainable forms of development (Roco 2012). To take one example, China–U.S. scientific collaboration, after declining slightly during a "nationalist phase" (2000–2005), is again increasing (Mehta et al. 2012); Shapira and Wang (2010) found that U.S.–China collaborations are among the densest of all inter-country collaborations. There are, of course, vast differences between such emerging economies such as China, India, Brazil, Argentina, and Chile—which already have fairly advanced scientific institutions—and the low-income countries of Latin America, Asia, and Africa, where scientific infrastructure is weak or entirely absent.

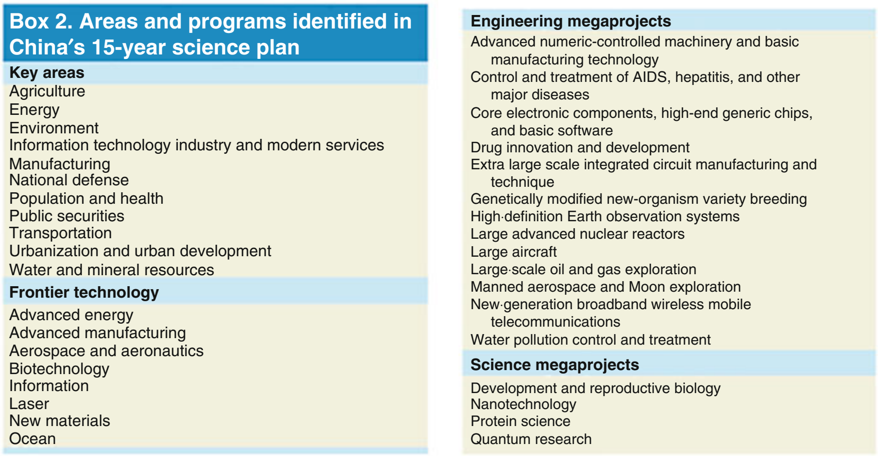
Some Outcomes

While the NNI has had clear success in supporting basic research, its payoff in terms of sustainable development, particularly developments that would benefit the Global South, is less clear. China can offer some useful lessons in this regard.

China has invested not only in basic research (China's nanotechnology-related scientific publications now equal or exceed those of the United States, although quality and impact are not as high), but also in potential for commercialization. China's 15-year *National Medium- and Long-Term Plan for Science and Technology Development, 2006–2020* (MLP) picks numerous winners for government funding, including eleven "key areas," eight "frontier technologies," thirteen "engineering megaprojects," and four "science megaprojects," one of which is nanotechnology (the other three are development and reproductive biology, protein science, and quantum research; see Fig. 10.13).

China's 12th Five-Year Plan (2011–2015) further identifies seven "strategic areas" for funding, including biotechnology and new materials, and emphasizes the importance of green development (the plan calls for reducing carbon emissions per unit of GDP by 17 %). China's overarching goal is to develop an "indigenous innovation" capability that would enable it to become less dependent on foreign technology transfer, transitioning from "made in China" to "designed in China."

Our own research suggests that China's investment in nanotechnology and other emerging technologies, while not without its challenges, is likely to pay off (Parker and Appelbaum 2012c, forthcoming; Appelbaum et al. 2011; Cao et al. 2013).



Box 2. Areas and programs identified in China's 15-year science plan

Key areas

Agriculture
Energy
Environment
Information technology industry and modern services
Manufacturing
National defense
Population and health
Public securities
Transportation
Urbanization and urban development
Water and mineral resources

Frontier technology

Advanced energy
Advanced manufacturing
Aerospace and aeronautics
Biotechnology
Information
Laser
New materials
Ocean

Engineering megaprojects

Advanced numeric-controlled machinery and basic manufacturing technology
Control and treatment of AIDS, hepatitis, and other major diseases
Core electronic components, high-end generic chips, and basic software
Drug innovation and development
Extra large scale integrated circuit manufacturing and technique
Genetically modified new-organism variety breeding
High-definition Earth observation systems
Large advanced nuclear reactors
Large aircraft
Large-scale oil and gas exploration
Manned aerospace and Moon exploration
New-generation broadband wireless mobile telecommunications
Water pollution control and treatment

Science megaprojects

Development and reproductive biology
Nanotechnology
Protein science
Quantum research

Fig. 10.13 Areas and programs identified in China's National Medium- and Long-term plan for science and technology development, 2006–2020 (Cao et al. 2006, 43; © American Institute of Physics, used by permission)

Its substantial investment in science research parks, such as Suzhou Industrial Park ("China's Silicon Valley") has proven attractive to foreign as well as local firms. (For a more detailed discussion, see Parker and Appelbaum 2012a, 148–149.) In a comparison of the U.S. and Chinese approach to the role of the state in driving high-tech research, development, and commercialization, we conclude, "the Chinese government [is] playing a facilitative role in providing the infrastructure, science parks, and greenfield university campuses that may eventually let a thousand nano-based products bloom" (Appelbaum et al. 2012, 127–128).

In my view, the U.S. should be investing more in bringing promising technologies to fruition, not just in terms of basic research, but also in terms of commercialization. The U.S. Government's support for small business innovation and commercialization (SBIR and STTR) programs should be significantly expanded. Additionally, U.S. visa policies need to be revised. Because U.S. universities remain among the best in the world for scientific innovation, a substantial percentage of science and engineering students enrolled in U.S. graduate programs come from other countries. According to an NSF study (2009), in 2006 foreign students earned a third of U.S. Ph.D. degrees in science and nearly two-thirds of U.S. Ph.D. degrees in engineering; one out of every three such students were from China (see also Matthews 2010). Current U.S. visa policies virtually assure that most of these students will return home after earning their degrees. China benefits from this short-sighted approach, enticing the best and brightest Chinese students and expatriates to return to China through highly attractive start-up packages (for example, the "Thousand Talents" and "Thousand Young Talents" Programs).

A Long-Term Perspective on Converging Technology, Innovation, and Sustainable Development in Emerging Economies

The world in the twenty-first century is facing extraordinary challenges. World population is projected to grow from the present seven billion to more than nine billion by 2050, with most of the growth occurring in developing countries. The probable detrimental impact of such growth on global warming and its associated climate change, potable water scarcity, food security, and public health issues are well known. The solutions to these challenges are both technological and political: while emerging technologies will clearly play a key role in their solution, it remains an open question whether the political (and economic) will exists to develop and utilize these technologies effectively.

The NNI should develop into an effective set of well-funded policies and programs in support of converging technologies, one that addresses basic research while providing the expanded support necessary to turn innovative ideas into practical results. Such an approach is necessary, I believe, given the central role that science and technology must play in achieving some degree of global economic, political, and environmental security in the twenty-first century.

Highlighted below are three important exploratory directions for converging knowledge and technology in the next 10–20 years:

- *"Open-source" scientific development*. Cross-border collaboration to solve the world's most pressing problems should be strongly encouraged. In the next 10–20 years, these problems will surely be in the four areas discussed above: energy/environment (sustainable development, as China, India, and other emerging economies expand); water purification/filtration; food security; and health. NSF could greatly expand its Partnerships for International Research and Education (PIRE) program, for example. Another approach would be to develop an open-source database to link experts and practitioners focused on the use of advanced technologies to address these issues. Such a database would be populated with the names of interested scientists and engineers, NGOs, sustainable development experts, potential funding sources, practitioners—all potential stakeholders in local sustainable development projects. It would be truly global, user-friendly, and designed in such a way that (for example) a rural Bolivian community with water purification problems could search out and identify a potential team whose expertise and practical experience would help develop viable solutions.
- *Participatory approaches to North/South collaboration*. This would involve developing appropriate technologies in full cooperation with developing countries, including learning from local practices (Lacy 2012). It is crucial to break down the traditional North/South relationship of technology transfer, where experts "parachute in" with an absence of local knowledge and participation, resulting in ill-suited—and hence ill-fated—solutions (Lewis 2012). The most advanced technologies, for example, may not always be the best suited answers to local needs. It is important to determine the most appropriate technology; simple water pumps may be more useful than advanced filtration technologies (Musaazi 2012). Should

the emphasis be on small-scale projects grounded in local communities, in which outside experts act in the service of local needs, or should the emphasis be on massive, government-led projects best suited to serving the needs of large numbers of people (Irvine-Halliday 2012; Wang and Huang 2012)?

- *Labor and EHS effects*. Expanded analysis of advanced technologies (such as nanotechnology) on labor markets and environmental health and safety is essential. Will more or fewer jobs result? What kinds of jobs will they be (Cozzens 2012; Foladori 2012; Invernizzi 2012; Invernizzi and Foladori 2005)? How can we better understand the largely unknown EHS issues of nano- and other emerging technologies—and how can we better communicate these effects to all stakeholders (Harthorn et al. 2012; Maynard et al. 2012)? While important work is now being done both on EHS issues (through the University of California and Duke University Centers for the Environmental Implications of Nanotechnology) and perceptions of EHS risk (by Harthorn and her collaborators at CNS-UCSB), very little work to date is being done on labor impacts.

10.9 International Perspectives

The following are summaries relevant to this chapter of discussions at the international regional WTEC NBIC2 workshops held in Leuven, Belgium, September 20–21, 2012; in Seoul, Korea, October 15–16, 2012; and in Beijing, China, October 18–19, 20110. Further details of those workshops are provided in Appendix A.

10.9.1 United States–European Union NBIC2 Workshop (Leuven, Belgium)

Panel members/discussants

Daan Schuurbiers, De Proeffabriek (Netherlands)
Albert Duschl, Paris Lodron University of Salzburg (EU)
Andy Miah, University of West Scotland (EU)
Alfred Nordmann, Darmstadt University of Technology (EU)
Anders Sandberg, Oxford University Future of Humanity Institute (EU)
Barbara Harthorn, University of California–Santa Barbara (U.S.)
Todd Kuiken, Woodrow Wilson International Center for Scholars (U.S.)
Jim Murday, University of Southern California (U.S.)
Mihail C. Roco, National Science Foundation and NNI (U.S.)

This group of scientists found consensus around three important themes: (1) human development, (2) sustainability and human development, and (3) co-evolution of human development and technology.

There is a difference of perspective on governance issues between the United States and the European Union. The former, as represented by George Whitesides' remarks in Leuven, seem to suggest that one should move ahead with converging technologies and implement governance processes when an opportunity develops. According to EU speakers, the EU position is that one needs to prove that some imagined advance in converging technologies will not be harmful before one moves on. This difference in perspective is certainly prevalent in the area of environmental risk management. A good middle ground is to implement adaptive management and governance, which really isn't brought out in great detail in the chapter.

For the first theme, the core idea was an emerging trend to use personalized molecular information to enhance both medical treatment and cognition. Other important trends were quality-of-life enhancements made possible by new prosthetic device technologies and regenerative medicine. Finally, the trend towards personalized innovative education was recognized. All of these trends reflect technological convergence.

For the second theme, the core idea was using convergent technologies to enhance human sustainability. One core idea was the use of waste and sea water as sources for human development. Another core idea was the reduction of energy imports while simultaneously reducing carbon footprints. The discussants imagined a future where megacities would be ubiquitous and materials would be infinitely renewable.

For the third theme, the central point was the accelerating co-evolution between human development and technology. The discussants agreed that the co-evolution would manifest in increased productivity, human capacity, and personalized lifelong education.

10.9.2 United States–Korea–Japan NBIC2 Workshop (Seoul, Korea)

Panel members/discussants

Sang-Ki Jeong (co-chair), Korea Institute of S&T Evaluation and Planning (KISTEP, Korea)
Mihail C. Roco (co-chair), National Science Foundation (U.S.)
Tomoji Kawai (co-chair), Osaka University (Japan)
Ji Woong Yoon (participant), Kyung Hee University (Korea)
Eugene Pak (participant), Seoul National University (Korea)

The viability of integrating NBIC technologies has been confirmed in multiple settings, but it was deliberately applied only occasionally (reactively). Concerns have grown about the impact of new technologies, particularly those affecting global environmental issues and energy, health, food, and human performance. There is an increasing emphasis on the roles of innovation, sustainability, and family wealth in evaluating new technologies. Innovative and societal implications are manifested in changing contexts: multiple S&T poles, transfer of wealth and initiative from West to East, demographic changes, and overall rapid developments.

By convergence, new outcomes are expected for user-friendly societal systems leading to advanced discovery, innovation, and entrepreneurial ecosystems. There is an increasing role for public/private partnerships in development of converging technologies, with emergence of new tools for participatory governance, e.g., games and social media. Studies have been performed in Korea on the main societal factors to effect societal trends. As a result, a government organization in the office of the Korean Prime Minister has been proposed to facilitate S&T convergence with a targeted implementation date at the end of 2012. Co-evolution between technology, values, and societal norms has been highlighted. The Japanese group provided as an example for converging knowledge and technology the work in robotics.

The main conclusions from the discussions are:

- Combined innovative and responsible governance is critical for competitiveness
- Governance should promote individual development
- Convergence should be guided by criteria such as sustainable development, individual privacy rights, international coordination, and international competitiveness
- Understanding opportunities/threats arising from changes in governance roles; traditional institutions have reduced role, being bypassed by social media-enabled movements

10.9.3 United States–China–Australia–India NBIC2 Workshop (Beijing, China)

Panel members/discussants

Xian-En Zhang (co-chair), Ministry of Science and Technology (China)
Mihail C. Roco (co-chair), National Science Foundation (U.S.)
Ron Johnston (co-chair), Australian Centre for Innovation

Others

Craig Johnson, University of Tasmania, Australia
Ke Xu, Suzhou Institute of Nano-Tech and Nano-Bionics (China)
Bo Tang (China)

Knowledge and converging technologies are progressing fast in China and Australia. Concerns about the impact of new technologies have grown, particularly those affecting health, food, and human performance.

There is an increasing emphasis on the roles of innovation and sustainability in evaluating new technologies. Also, there is an increasing emphasis on the roles of *innovation and sustainability* in evaluating new technologies.

Examples were presented of how investment policies in multidisciplinary/multi-application R&D centers have been developed for China. Three main drivers are global issues (energy, resources, etc.), science breakthroughs (in brain research, single cell biology, etc.), and human dimensions (aging, cognitive and communication capacity, etc.). Combining specialization with converging thinking (in time, across fields) is an essential aspect.

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