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THE SOCIETAL IMPLICATIONS OF NANOTECHNOLOGY

HEARING

BEFORE THE

COMMITTEE ON SCIENCE
HOUSE OF REPRESENTATIVES

ONE HUNDRED EIGHTH CONGRESS

FIRST SESSION

APRIL 9, 2003

Serial No. 108–13

Printed for the use of the Committee on Science

Available via the World Wide Web: http://www.house.gov/science

U.S. GOVERNMENT PRINTING OFFICE

86–340PS WASHINGTON : 2003

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April 9, 2003

THE SOCIETAL IMPLICATIONS OF NANOTECHNOLOGY

WEDNESDAY, APRIL 9, 2003

HOUSE OF REPRESENTATIVES,
COMMITTEE ON SCIENCE,
Washington, DC.

The Committee met, pursuant to call, at 10:15 a.m., in Room 2318 of the Rayburn House Office Building, Hon. Sherwood L. Boehlert (Chairman of the Committee) presiding.

COMMITTEE ON SCIENCE
U.S. HOUSE OF REPRESENTATIVES

The Societal Implications of Nanotechnology

Wednesday, April 9, 2003
10:00 AM
2318 Rayburn House Office Building (WEBCAST)

Witness List

Mr. Ray Kurzweil
Chairman and CEO
Kurzweil Technologies, Inc.

Dr. Vicki Colvin
Executive Director
Center for Biological and Environmental Nanotechnology
Associate Professor of Chemistry
Rice University

Dr. Langdon Winner
Professor of Political Science
Department of Science and Technology Studies
Rensselaer Polythecnic Institute

Ms. Christine Peterson
President
Foresight Institute

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HEARING CHARTER

COMMITTEE ON SCIENCE
U.S. HOUSE OF REPRESENTATIVES

The Societal Implications of Nanotechnology

WEDNESDAY, APRIL 9, 2003
10:00 A.M.–12:00 P.M.
2318 RAYBURN HOUSE OFFICE BUILDING

1. Purpose

On Wednesday April 9, 2003, the House Science Committee will hold a hearing to examine the societal implications of nanotechnology and to consider H.R. 766, *The Nanotechnology Research and Development Act of 2003,* in light of those implications.

2. WITNESSES

Mr. Ray Kurzweil is Founder, Chairman and CEO of Kurzweil Technologies, Inc., a software development firm. A pioneer in artificial intelligence, he is the author of *The Age of Intelligent Machines* (1990) and *The Age of Spiritual Machines* (1999). He received the 1999 National Medal of Technology and in 2002 was inducted into the National Inventors Hall of Fame, for his 1976 invention of the Kurzweil Reading Machine, the first device to transform print into computer-spoken words, enabling blind and visually impaired people to read printed materials. Since 1973, he has founded nine companies.

Dr. Vicki Colvin is the Executive Director of the Center for Biological and Environmental Nanotechnology and Associate Professor of Chemistry at Rice University. Research underway at the center focuses on nanomaterials' behavior in the environment and the body and considers risk assessment and safety factors.

Dr. Langdon Winner is Professor of Political Science in the Department of Science and Technology Studies at Rensselaer Polytechnic Institute in Troy, New York where he serves as co-director of the newly founded Center for Cultural Design. He is a political theorist who focuses on social and political issues that surround modern technological change.

Ms. Christine Peterson is cofounder and President of Foresight Institute. She focuses on making nanotechnology understandable, and on clarifying the difference between near-term commercial advances and the "Next Industrial Revolution" arriving in the next few decades. Foresight Institute has developed guidelines that include assumptions, principles, and some specific recommendations intended to provide a basis for responsible development of molecular nanotechnology.

3. OVERARCHING QUESTIONS

The hearing will address the following overarching questions:

1. What are the concerns about existing and potential applications of nanotechnology?
2. How is it possible to anticipate the consequences of technology development?
3. How can research and debate on societal and ethical concerns be integrated into the research and development process, especially into projects funded by the Federal Government?

4. BRIEF OVERVIEW

- Nanotechnology is the science of manipulating and characterizing matter at the atomic and molecular level. It is one of the most exciting fields of science today, involving a multitude of science and engineering disciplines, with widespread applications in electronics, advanced materials, medicine, and information technology. The promise of nanotechnology to accelerate technological change has prompted some to advise caution about pursuing rapid innovation without some understanding of where it might lead us.

- In the April, 2000 issue of Wired magazine, Bill Joy, Chief Scientist for Sun Microsystems, published an article entitled *Why the Future Doesn't Need Us* which postulated that "our most powerful 21st Century technologies—robotics, genetic engineering, and nanotechnology—are threatening to make humans an endangered species." Joy argued that the convergence of information technology, biotechnology, and nanotechnology could result in intelligent, self-replicating, nanoscale robots with potentially destructive consequences. Many experts have dismissed Joy's prognostications as better suited to the realm of science fiction, but his article did energize a debate on the potential impact of rapid technology development.
- In November, 2002, Michael Crichton published *Prey,* a science fiction novel in which self-replicating, intelligent, and rapidly evolving nanoscale robots pose a mortal threat to humans and to the environment. Although fiction, *Prey* brought Bill Joy's concerns to a wider public and reinvigorated the debate over the possible negative consequences of future developments in information technology, biotechnology, and nanotechnology.
- The National Academy of Sciences, in its recent (2002) review of the National Nanotechnology Initiative, recommended that the research on the societal implications of nanotechnology be integrated into nanotechnology research and development programs in general. The Academy noted that rapid technology development will affect how we educate new scientists and engineers, how we prepare our workforce, and how we plan and manage research. Moreover, accelerated nanotechnology developments could have broader social and economic consequences that may afford an opportunity to develop a greater understanding of how technical and social systems affect one another.
- One of the more salient concerns is the possible environmental or health impact of nanotechnology materials. Nanoscale particles, or nanoparticles, because of their small size, may readily enter living systems with potentially toxic results. While few comprehensive studies have been completed, early research suggests that some common nanotechnology materials may be biologically inert and thus pose little threat. Nonetheless, new materials can interact with the environment or with living systems in unexpected ways.
- In March of 2001, the National Science Foundation (NSF) convened a workshop on the societal implications of nanotechnology. Workshop participants recommended that social and economic research on nanotechnology be included in the research conducted at NSF-sponsored nanotechnology centers.
- Witnesses at the Science Committee's March 19 hearing on H.R. 766, *The Nanotechnology Research and Development Act of 2003,* concurred with the recommendation of the NSF workshop participants and testified that research on the societal implications of nanotechnology should be an integral part of the national nanotechnology research and development program. H.R. 766 includes a provision that establishes a research program to identify societal and ethical concerns related to nanotechnology and requires that such research be integrated into nanotechnology R&D programs insofar as possible.

5. BACKGROUND

In its recent review of the National Nanotechnology Initiative, the National Academy of Sciences noted that the social and economic consequences of nanotechnology promise to be diverse, difficult to anticipate, and sometimes disruptive. Some experts suggest that nanotechnology will lead us to the next industrial revolution.

According to the Academy review panel:

> . . .if the nanotechnology revolution lives up to the hype comparing it to the industrial revolution, it will also transform and perturb labor and the workplace, introduce new worker safety issues, affect the distribution of wealth within and between nations, and change a variety of social institutions, including our medical system and the military. While these kinds of transformations occurred with other technological advances and were managed reasonably well, there are reasons to believe the transformation propagated by a nanotechnology revolution may be particularly challenging. Nanotechnology is likely to affect and transform multiple industries and affect significant numbers of workers and parts of the economy. Technological acceleration, the increasing rate of discovery in some disciplines, most notably biology, and the synergy provided by improvements in information and computing technologies, have the potential to compress the time from discovery to full deployment for nanotechnology, thereby shortening the time society has to adjust to these changes. Speculation about unintended consequences of nanotechnology, some of it informed, but a lot of it

> wildly uninformed, has already captured the imagination and, to some extent, the fear of the general public.
>
> Some technologists, such as those in the nuclear power and genetically modified foods industries, have ignored these kinds of challenges and suffered the consequences. Others, most notably those in the molecular biology community, have attempted to address the issues and to use their understanding to stimulate an informed and objective dialogue about the choices that can be made and the directions taken.

The Academy review panel noted that nanotechnology provides a unique opportunity to develop a better understanding of how technical and social systems affect one another.

> We currently do not have a comprehensive and well-established knowledge base on how social and technical systems affect each other in general, let alone for the specific case of nanotechnology. This state of affairs is a byproduct of not having a chance to examine these interactions until the systems are well established and of simply not investing sufficient resources in these activities. However, nanotechnology is still in its infancy. Thus, a relatively small investment now in examining societal implications has the potential for a big payoff.

The Academy review panel further noted that while the National Science Foundation explicitly included societal implications in its solicitations for nanotechnology research during fiscal year (FY) 2001, few proposals were submitted and none was funded. Within the Foundation, none of the FY 2001 nanotechnology research funds were allocated to the Directorate of Social, Behavioral and Economic Sciences. According to the Academy review panel:

> [The Directorate of Social, Behavioral and Economic Sciences (SBES) is] the most capable and logical directorate to lead these efforts. As a consequence [of not allocating nanotechnology funds to SBES], social science work on societal implications could be funded [at NSF] in one of two ways: (1) it could compete directly for funding with physical science and engineering projects through a solicitation that was primarily targeted at that audience or (2) it could be integrated with a nanotechnology science and engineering center.
>
> There are a number of reasons both funding strategies failed to promote a strong response from the social science community. First, given the differences in goals, knowledge bases, and methodologies, it was probably very difficult for social science group and individual proposals to compete with nanotechnology science and engineering proposals submitted to the physical science and engineering directorates. In addition, while NSF nanotechnology proposals were required to include an educational component and/or a component aimed at the development of a skilled workforce or an informed public, studies of societal implications was only one of six optional activities (including international collaboration, shared experimental facilities, systems-level focus, proof-of-concept testbeds, and connection to design and development activities) that individual proposals could include. Not surprisingly, while essentially every proposal included an educational component, and many included familiar practices like testbeds, very few included a social science component. Finally, NSF's review committees and site visit teams [to review center proposals] did not include social scientists.
>
> Thus, although NSF appears to have made a good faith effort to include social science proposals in its agency-wide solicitation, its internal funding strategy and the way the solicitation was framed probably undermined its attempts to support work in this area.

Since the release of the Academy study, new NSF solicitations (FY03) require proposals for nanotechnology fabrication centers to include a societal implications dimension and NSF's Directorate for Social, Behavioral, and Economic Sciences will be involved in proposal review.

NSF also supports a science and technology center—the Center for Biological and Environmental Nanotechnology at Rice University—that seeks to foster the development of nanotechnology through an integrated set of research programs that aim to address the scientific, technological, environmental, human resource, commercialization, and societal barriers that hinder the transition from research to useful technology.

6. WITNESS QUESTIONS

The witnesses were asked to address the following questions in their testimony:

Questions for Mr. Ray Kurzweil

- What are the concerns about existing and potential applications of nanotechnology?
- How is it possible to anticipate the consequences of technology development?
- To what extent and how should the policy makers communicate with the public to facilitate a responsible debate about the adoption of nanotechnology innovations into society? What role should researchers in nanotechnology play? What role should the private sector play?
- How can research and debate on societal and ethical concerns be integrated into the research and development process?

Questions for Dr. Vicki Colvin

- What are the concerns about existing and potential applications of nanotechnology?
- How is it possible to anticipate the consequences of technology development?
- To what extent and how should the policy makers communicate with the public to facilitate a responsible debate about the adoption of nanotechnology innovations into society? What role should researchers in nanotechnology play? What role should the private sector play?
- How can research and debate on societal and ethical concerns be integrated into the research and development process?
- How is the work of the Rice Center for Biological and Environmental Nanotechnology integrated into the programs of the National Nanotechnology Initiative?

Questions for Dr. Langdon Winner

- What factors influence the successful adoption of new technologies into society? What questions should be asked during the research and development phase to help minimize the potentially disruptive impact of transformational technology developments?
- What are the current concerns about existing and potential applications of nanotechnology science and engineering?
- How can research on the societal and ethical concerns relating to nanotechnology developments be integrated into the research and development process?

Questions for Ms. Christine Peterson

- What factors will influence the successful adoption of nanotechnology applications into society? What questions should be asked during the research and development phase to encourage responsible integration of nanotechnology innovations into society?
- What is the status of the adoption of nanotechnology applications? What policies might facilitate adoption of new technologies? What are the potential roadblocks? For example, will there be a workforce with appropriate technical skills?
- What role will the private sector play in the debate on societal and ethical concerns about existing and potential applications of nanotechnology?

APPENDIX I

Table 1. National Nanotechnology Initiative Funding ($$ Millions)

NNI AGENCY	FY 2001 Enacted	FY 2002 Enacted	FY 2003 Enacted	FY 2004 Requested	H.R. 766 for FY04
NSF	150	199	221	249	350*
DOD	123	180	243	222	--
DOE	88	91	133	197	197
NIH	40	41	65	70	--
DOC	33	38	69	62	62
NASA	22	46	33	31	31
USDA	2	2	1	10	--
EPA	5	--	6	5	5
DHS (FAA/TSA)	--	2	2	2	--
DOJ	1	1	1	1	--
TOTAL	**464**	**600**	**774**	**849**	

Note: H.R. 766 authorizes in statute a national nanotechnology R&D program to include all participating agencies as designated by the President, but appropriations are authorized only for those agencies within the jurisdiction of the Science Committee.
*FY04 authorizations in H.R. 766 conform to the President's budget request except for the NSF nanotechnology authorization, which conforms to the National Science Foundation Act of 2002 signed into law by the President last December, P.L. 107-368.

APPENDIX II

SECTION-BY-SECTION ANALYSIS OF THE NANOTECHNOLOGY R&D ACT OF 2003

Sec. 1. Short Title

"Nanotechnology Research and Development Act of 2003."

Sec. 2. Definitions

Defines terms used in the text.

Sec. 3. National Nanotechnology Research and Development Program

Establishes an interagency R&D program to promote and coordinate federal nanotechnology research, development, demonstration, education, technology transfer, and commercial application activities. The program will provide sustained support for interdisciplinary nanotechnology R&D through grants to researchers and through the establishment of interdisciplinary research centers and advanced technology user facilities.

Establishes a research program to identify societal and ethical concerns related to nanotechnology and requires that such research be integrated into nanotechnology R&D programs insofar as possible.

Establishes an interagency committee, chaired by the Director of the Office of Science and Technology Policy, and composed of representatives of participating federal agencies, as well as representatives from the Office of Management and Budget, to oversee the planning, management, and coordination of all federal nanotechnology R&D activities. Requires the Interagency Committee to establish goals and priorities, establish program component areas to implement those goals and priorities, develop a strategic plan to be updated annually, consult widely with stakeholders, and propose a coordinated interagency budget for federal nanotechnology R&D.

Sec. 4. Annual Report

Requires the Office of Science and Technology Policy to submit an annual report, at the time of the President's budget request to Congress, describing federal nanotechnology budgets and activities for the current fiscal year, and what is proposed for the next fiscal year, by agency and by program component area. Requires that the report include an analysis of the progress made toward achieving the goals and priorities established for federal nanotechnology R&D, and the extent to which the program incorporates the recommendations of the Advisory Committee (established in Sec. 5).

Sec. 5. Advisory Committee

Establishes a Presidentially-appointed advisory committee, consisting of non-federal experts, to conduct a broad assessment of federal nanotechnology R&D activities and issue a biennial report.

Sec. 6. National Nanotechnology Coordination Office

Establishes a National Nanotechnology Coordination Office with full-time staff to provide technical and administrative support to the Interagency Committee and the Advisory Committee, to serve as a point of contact for outside groups, and to conduct public outreach.

Sec. 7. Authorization of Appropriations

Authorizes appropriations for nanotechnology R&D programs at the National Science Foundation, the Department of Energy, the National Aeronautics and Space Administration, the National Institute of Standards and Technology, and the Environmental Protection Agency (see table below).

Agency	FY04	FY05	FY06
NSF	$350 M	$385 M	$424 M
DOE	$197 M	$217 M	$239 M
NASA	$ 31 M	$ 34 M	$ 37 M
NIST	$ 62 M	$ 68 M	$ 75 M
EPA	$ 5 M	$ 5.5 M	$ 6 M
Total	**$645 M**	**$709.5 M**	**$781 M**

Sec. 8. External Review of the National Nanotechnology Research and Development Program

Requires the Director of the Office of Science and Technology Policy to contract with the National Academy of Sciences to conduct a triennial review of federal nanotechnology R&D programs including technical progress, managerial effectiveness, and adequacy in addressing societal and ethical concerns.

Chairman BOEHLERT. We will come to order. A little housekeeping first. The Chair will recognize the distinguished Ranking Member, Mr. Hall of Texas, for the purpose of an appointment.

Mr. HALL. Mr. Chairman, thank you. I ask unanimous consent that my honored colleague from Texas, my neighbor in Texas, Ms. Eddie Bernice Johnson, be elected to membership on the Subcommittee on Space and Aeronautics in order to fill an existing democratic vacancy.

Chairman BOEHLERT. Without objection, so ordered.

Mr. HALL. Thank you.

Chairman BOEHLERT. Ms. Johnson, welcome. I want to welcome everyone here this morning for this important hearing. It is rare that Congress gets, or I should say takes, the opportunity to take a step back and think about the consequences of technological change even though they are driving—they are a driving force in our society. So I am eager to have this hearing.

I just wanted to say that we should approach today's hearing with evenhandedness and humility. With evenhandedness, because technology, like most human endeavors, inevitably leads to both positive and negative consequences, but one thing we can be sure of is that nanotechnology will be neither the unallied boom predicted by technophiles nor the unmitigated disaster portrayed by technophobes. The truth will be in between, and it is worth probing. But how good are we at probing it? Here is where the humility comes in. As Yogi Berra is supposed to have said, "It is always difficult to make predictions, especially about the future." And certainly, I might point out that he is one of the greats of the Yankees, which occupy the lofty position of first place in the American league.

And indeed, our record, when it comes to technology, is not very good, but how good can we expect it to be? The social consequences of technology, the most subtle and far-reaching impacts, are the most difficult to predict and even more difficult to forestall. But that is not a reason to do nothing. We have to figure out as much as we can about the potential impacts of technology and plan accordingly. The most tangible, direct impacts, like harms to the environment or health, should be susceptible to study, even if we don't get everything right, right from the beginning.

So I hope we have a thorough, in-depth discussion this morning that avoids easier answers and that makes distinctions between different types of potential consequences: those that are social, those that raise ethical questions, those that involve purposeful misuse of technology, those that relate to government, and so on, because each type of consequence raises its own set of questions. I think those questions are worth investigating, not just about nanotechnology, but about all technologies. And I am pleased that H.R. 766, the nanotechnology bill that I have introduced with Mr. Honda, authorizes research grants on societal and ethical consequences and requires that that research be integrated with the physical science research. We will markup that bill on April 30, and I expect it to be on the House Floor the following week.

[See Appendix 1: Additional Material for the Record for H.R. 766.]

Chairman BOEHLERT. As many people here know, the most extravagant fear about nanotechnology is that it will yield nanobots that will turn the world into gray goo. That is not a fear I share, but I do worry that the debate about nanotechnology could turn into gray goo with its own deleterious consequences. I am hopeful that today's hearing on H.R. 766 will keep the debate solid. We know it will be lively.

Thank you very much.

[The prepared statement of Mr. Boehlert follows:]

PREPARED STATEMENT OF CHAIRMAN SHERWOOD BOEHLERT

I want to welcome everyone here this morning for this important hearing. It's rare that Congress gets—or, I should say, takes—the opportunity to take a step back and think about the consequences of technological change, even though they are a driving force in our society. So I'm eager to get this hearing started.

I just want to say that we should approach today's hearing with even-handedness and humility. With even-handedness because technology, like most human endeavors, inevitably leads to both positive and negative consequences. The one thing we can be sure of is that nanotechnology will be neither the unalloyed boon predicted by technophiles nor the unmitigated disaster portrayed by technophobes. The truth will be in between, and it is worth probing.

But how good are we at probing it? Here's where the humility comes in. As Yogi Berra is supposed to have said, "It's always difficult to make predictions, especially about the future." And indeed our record when it comes to technology is not very good. But how good can we expect to be? The social consequences of technology—the most subtle and far-reaching impacts—are the most difficult to predict and even more difficult to forestall.

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As many people here know, the most extravagant fear about nanotechnology is that it will yield nanobots that will turn the world into "gray goo." That's not a fear I share, but I do worry that the debate about nanotechnology could turn into "gray goo"—with its own deleterious consequences. I'm hopeful that today's hearing and H.R. 766 will keep the debate solid and lively. Thank you.

Chairman BOEHLERT. And the Chair recognizes Mr. Hall.

Mr. HALL. Mr. Chairman, I am pleased to join you in the welcoming of these witnesses here today. At the previous hearing, we reviewed the current Federal nanotechnology research effort and received comments and advice on new authorizing legislation, which the Committee will soon be marking up. I think it is fair to say that the previous hearing revealed strong support for the initiative and for the legislation.

It is clear that nanotechnology has great promise that will have enormous consequences for the information industry, for manufacture, for medicine and health. Indeed, the scope of the technology is so broad; it is to leave virtually no product untouched. The fact that nanotechnology has such broad potential argues for careful consideration and careful attention to how it may affect society, and in particular, attention to potential downsides of the technology.

While some concerns have already been raised that seem more to—in the realm of science fiction, there are also very real issues with the potential health and environmental effects of nanosized particles. Some examples will be brought out, I think, in today's testimony. I believe it is important for the successful development of nanotechnology that potential problems be addressed from the beginning in a straightforward and an open way. We know too well that negative public perceptions about the safety of a technology can have serious consequences for its acceptance and for its use. This has been the case in such technologies as nuclear power, genetically modified foods, and stem cell therapies.

Research is needed to provide understanding of potential problems arising from nanotechnology applications in order to allow informed judgments to be made about risk and cost benefit tradeoffs for specific implementations of the technology. An effort must be made by the research community to open lines of communication with the public to make clear that potential safety risks are being explored and not ignored. We can't once—down again go down a path where the research community simply issues a statement to the public, "Trust us. It is safe." The research plan for the National Nanotechnology Initiative has identified the need for research and education activities that address societal impacts of the technology, and I hope that today's hearing will help identify the questions that need to be asked, who should be involved, and the level of resources needed. Excuse me.

I also ask our witnesses for any recommendations they may have for improvements to the authorizing legislation that will help strengthen the societal impact component of the initiative. And I once again thank you, Mr. Chairman, for calling this hearing. I appreciate the attendance of our witnesses today. I realize they are important people. They have important jobs. It takes time to prepare, time to come here, time to give us this, and we are grateful to you. And we thank you for it. Mr. Chairman, with that, I yield back my time.

[The prepared statement of Mr. Hall follows:]

PREPARED STATEMENT OF REPRESENTATIVE RALPH M. HALL

I am pleased to join the Chairman in welcoming our witnesses to the Committee's second hearing on the National Nanotechnology Initiative.

At the previous hearing we reviewed the current federal nanotechnology research effort and received comments and advice on new authorizing legislation, which the Committee will soon be marking up. I think it is fair to say that the previous hearing revealed strong support for the initiative and the legislation.

It is clear that nanotechnology has great promise. It will have enormous consequences for the information industry, for manufacturing, and for medicine and health. Indeed, the scope of this technology is so broad as to leave virtually no product untouched.

The fact that nanotechnology has such broad potential argues for careful attention to how it may affect society, and in particular, attention to potential downsides of the technology. While some concerns have already been raised that seem more in the realm of science fiction, there are also very real issues with the potential health and environmental effects of nanosized particles. Some examples will be brought out in today's testimony.

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Research is needed to provide understanding of potential problems arising from nanotechnology applications in order to allow informed judgments to be made about risk and cost/benefit tradeoffs for specific implementations of the technology. And efforts must be made by the research community to open lines of communication with the public to make clear that potential safety risks are being explored and not ignored.

We cannot once again go down the path where the research community simply issues a statement to the public: Trust us, it's safe.

The research plan for the National Nanotechnology Initiative has identified the need for research and education activities that address societal impacts of the technology. I hope that today's hearing will help identify the questions that need to be asked, who should be involved, and the level of resources needed.

I also ask our witnesses for any recommendations they may have for improvements to the authorizing legislation that will help strengthen the societal impacts component of the initiative.

I want to thank the Chairman for calling a hearing on this important aspect of the nanotechnology initiative. I appreciate the attendance of our witnesses today, and I look forward to our discussion.

[The prepared statement of Mr. Smith follows:]

PREPARED STATEMENT OF REPRESENTATIVE NICK SMITH

This morning we meet for our second hearing to review H.R. 766, *The Nanotechnology Research and Development Act of 2003*. At the first hearing we examined the state of nanotechnology, its short-term and long-term potential, and the importance of establishing a government coordination mechanism for federal support of the science. Today we will examine the potential negative implications of nanotechnology on society and the environment.

The first hearing provided a glimpse of the incredible promise that nanotechnology holds to improve our lives, strengthen our economy, and address a countless array of societal problems. When this promise comes to fruition, I believe that nanotechnology and biotechnology will become the most important technological advancement since the information technology revolution of the 1990s.

While it is difficult to predict how long it may take for nanotechnology research and development to lead to significant breakthrough innovations, it is not difficult to understand that the Federal Government can accelerate this development by providing strong, coordinated support of fundamental nanotechnology research. This is the vision set forth in H.R. 766, that many of us on the Committee have co-sponsored.

One of the key components of the research effort authorized by H.R. 766, and the topic of our hearing today, is research into the societal implications of nanotechnology. This research will help us to better understand the very real societal and ethical concerns that will arise in the wake of nanotech's inevitable impact on our lives. I strongly support these provisions of H.R. 766 and I believe it is critical that we address these issues so we can ensure that the general public can take comfort in knowing the products have been thoroughly tested and proved safe.

This effort will go a long way in limiting the effectiveness of groups that seek to unfairly portray nanotechnology R&D as too dangerous to press forward with. These organizations attempt to create fear and paranoia by blurring the lines between legitimate societal risks and imaginary science fiction. Some groups have even gone to the extreme of calling for a complete moratorium on all nanotechnology research and commercialization, unfairly framing nanotechnology as "the next asbestos."

Unfortunately, these scare-mongering tactics of widespread misinformation campaigns can be very effective, and in fact often help raise significant amounts of money for the organization, with which they use to attack the science further. This same strategy has been very successful in damaging the reputation of biotechnology—delaying research, development, and adoption of several safe and beneficial products, most notably pest resistant GM crops in Africa.

As a passionate supporter of science rather than emotion governing the advancement of biotechnology, I believe it is important that safe and beneficial nanotechnology innovations do not suffer the problems of emotion and delay that hindered biotechnology applications before them. This will require that we conduct research into areas of societal and ethical concern, educate the public on the safety of these products, and maintain a regulatory framework that keeps pace with the development of new and unique nanotechnology products.

We must also recognize that the precautionary principle approach of not adopting new technology unless "zero risk" has been established is unrealistic. Instead, the question of moving ahead with new nanotechnology applications should not be decided on whether or not a risk might exist, but rather whether or not the benefits *outweigh* the risks. This approach will help ensure that policy decisions are driven by sound science, not unscientific alarmist rhetoric.

Perhaps these efforts would be aided if we called for nanotechnology research based on regulatory scientific evaluation and safeguards. It might be difficult to stop negative rhetoric , but until committed skeptics of nanotechnology can provide sound scientific evidence to support their gloom and doom forecasts, we should make every effort to see their arguments are countered vigorously with scientific information.

We have an esteemed panel of experts on these topics with us here today, and I look forward to a productive discussion.

[The prepared statement of Mr. Costello follows:]

PREPARED STATEMENT OF REPRESENTATIVE JERRY F. COSTELLO

Good morning. I want to thank the witnesses for appearing before this committee to discuss the possible societal impacts and ethical concerns related to nanotechnology research and applications. Understanding the discoveries from nanotechnology will contribute to improvements in medicine, manufacturing, high-performance materials, information technology, and environmental technologies.

Nanotechnology can best be considered as a "catch-all" description of activities at the level of atoms and molecules that have applications in the real world. A variety of nanotechnology products are already in development or on the market, including stain-resistant, wrinkle free pants and ultraviolet-light blocking sunscreens.

However, specific applications of nanotechnology can have implications that cut two ways. For example, new nanoscale medical detection devices allow the identification of an individual's genetic predisposition to a disease. This raises issues of privacy and could threaten the stability of health insurance, which is based on uncertainty and spreading risk across the population. Further, nanotechnology developments have produced and will continue to produce rapid technological changes that can threaten the social structure, economic stability, and spiritual beliefs and values.

I am interested to know what types of changes are needed to respond or adapt to societal changes that nanotechnology developments may bring. In addition, I am interested to learn more about public education efforts about nanotechnology.

I thank the witnesses for appearing before our committee and look forward to their testimony.

[The prepared statement of Ms. Johnson follows:]

PREPARED STATEMENT OF REPRESENTATIVE EDDIE BERNICE JOHNSON

Thank you, Mr. Chairman for calling this meeting today. I welcome our distinguished guests and would like to thank you for agreeing to testify here today on the importance of the National Nanotechnology Initiative.

The purpose of this hearing is to examine federal nanotechnology research and development. Also today, we will consider H.R. 766, the Nanotechnology Research and Development Act of 2003. I am a proud original co-sponsor of this legislation.

Nanotechnology is the act of manipulating matter at the atomic scale. Regardless of the diverse opinions on the rate at which nanotechnology will be implemented, people who make it a habit to keep up with technology agree on this: it is a technology in its infancy, and it holds the potential to change *everything*.

Research in nanoscience is literally exploding, both because of the intellectual allure of constructing matter and molecules one atom at a time, and because the new technical capabilities permit creation of materials and devices with significant societal impact. The rapid evolution of this new science and the opportunities for its application promise that nanotechnology will become one of the dominant technologies of the 21st century. Nanotechnology represents a central direction for the future of chemistry that is increasingly interdisciplinary and ecumenical in application.

I agree with the assessment that nanotechnology is one of the most promising and exciting fields of science today. I look forward to working with this committee on its advancement.

[The prepared statement of Mr. Honda follows:]

PREPARED STATEMENT OF REPRESENTATIVE MICHAEL M. HONDA

Christine Peterson is co-founder and President of Foresight Institute, a Silicon Valley based nonprofit that educates the public, the technical community, and policy-makers on nanotechnology and its long-term effects.

Christine focuses on making nanotechnology understandable, and on clarifying the difference between near-term commercial advances and the "Next Industrial Revolution" arriving in the next few decades.

With Eric Drexler and Gayle Pergamit, she wrote *Unbounding the Future: the Nanotechnology Revolution,* which sketches nanotechnology's potential environmental and medical benefits as well as possible abuses.

Christine tells me that her work is motivated by a desire to help Earth's environment and traditional human communities avoid harm and instead benefit from expected dramatic advances in technology.

I believe we have a unique opportunity to consider the possible social, legal, ethical, and philosophical issues that might arise as the nanotechnology industry matures before they occur, and it is our duty to do so.

Similar opportunities were missed in the fields of molecular genetics and the development of the Internet, and now we wrestle with issues such as genetic screening, privacy, and intellectual property.

I hope that we develop an approach to dealing with the coming challenges that allows us to achieve the vision of the future that Christine has described, in which nanotechnology benefits both humans and the natural environment.

I look forward to hearing her thoughts on how we can achieve this. Thank you Mr. Chairman.

Chairman BOEHLERT. Thank you very much, Mr. Hall. And we have one panel of very distinguished people who are serving as resources to this committee. And I very much appreciate it, and it is a tradition of the Committee just to introduce witnesses with their name and assume the whole world knows a lot about them. And we take for granted our witnesses, quite frankly. I have to confess that. These people that are witnesses are all very distinguished people in their professions, and they are part of the education of the Congress, so we deeply appreciate your availability and your guidance to us as we try to shape responsible public policy.

Our witnesses today consist of Mr. Ray Kurzweil, Founder, Chairman, and CEO of Kurzweil Technologies, Inc., a software development firm. A pioneer in artificial intelligence, he is the author of "The Age of Intelligent Machines" and "The Age of Spiritual Machines." He received the 1999 National Medal of Technology and in 2002, he was inducted into the National Inventors Hall of Fame for his 1976 invention of the Kurzweil Reading Machine, the first device to transform print into computer spoken words, enabling blind and visually impaired people to read printed materials. Since 1973, he has founded nine companies. Mr. Kurzweil, I thank you for being with us.

Dr. Vicki Colvin is the Executive Director for the—for the Center for Biological and Environmental Nanotechnology and Associate Professor of Chemistry at Rice University. Research underway at the center focuses on nanomaterials' behavior in the environment and the body and considers risk assessment and safety factors. Dr. Colvin.

Dr. Langdon Winner is Professor of Political Science in the Department of Science and Technology Studies at Rensselaer Polytechnic Institute in Troy, the great Empire State of New York. Pardon a little pride there. We just happen to have the national basketball champions in New York and I attribute to the Syracuse Orangemen. And we have the New York Yankees, which are in first place, where they belong. But we also have a wonderful resource.

Mr. SHERMAN. Mr. Chairman, who are the national champions of basketball—of baseball?

Chairman BOEHLERT. The national champions? That was last year.

Mr. SHERMAN. Well, that would be the most recent year.

Chairman BOEHLERT. Dr. Winner is a political theorist who focuses on social and political issues that surround modern technological change. And for the purpose of an introduction of our final witness, I am pleased to call on my partner, the distinguished gentleman from California, Mr. Honda.

Mr. HONDA. Thank you, Mr. Chairman and Ranking Member. I—before I start, I just want to make a personal comment of the Chair that your comments and—your personal comments regarding the panel is well founded. And I appreciate the time that you take to make sure that the folks do know their background and their contributions and that your mom would be real proud of you.

It is my pleasure, Mr. Chairman and Ranking Member, to introduce Christine Peterson is—she is a cofounder and President of Foresight Institute, a Silicon Valley based non-profit that educates the public, the technical community, and the policy makers on nanotechnology and its long-term effects. Christine focuses on making nanotechnology understandable and on clarifying the difference between near-term commercial advances and the "Next Industrial Revolution" arriving in the next few decades. With Eric Drexler and Gayle Pergamit, she wrote "Unbounding the Future: The Nanotechnology Revolution", which sketches nanotechnology's potential environmental and medical benefits as well as possible abuses.

Christine tells me that her work is motivated by a desire to help Earth's environment and traditionally human communities avoid harm, and instead benefit from expected dramatic advances in technology.

I feel that we have a unique opportunity to consider the possible social, legal, ethical, and philosophical issues that might arise as the nanotechnology industry matures before they occur. And it is our duty to do so. Similar opportunities were missed in the fields of molecular genetics and the development of the Internet. And now we wrestle with these issues such as genetic engineering, genetic screening privacy, and intellectual property. I hope that we develop an approach to dealing with the coming challenges that allows us to achieve the vision of the future that Christine has described in which nanotechnology benefits both humans and the natural environment.

I look forward to hearing her thoughts on how we can achieve this. Mr. Chairman, thank you for this opportunity.

Chairman BOEHLERT. Thank you very much. And now for the panel, your record—your statement will appear in the record at this juncture in its entirety. We would ask that you try to summarize it, not because we want to have a brief session, but because we want to allow ample opportunity for questions. We will give you, as a guide, five or six or seven minutes. We are not going to be arbitrary. It always boggles my mind that we have experts like you come from afar to guide us and then we say, "Tell us everything we need to know in 300 seconds or less." So we will be lenient with you. And to Mr. Honda, I would say my mother would be proud, you are right, and surprised as hell that I amounted to anything.

Mr. Kurzweil, you are up first.

STATEMENT OF MR. RAYMOND KURZWEIL, CHAIRMAN AND CEO, KURZWEIL TECHNOLOGIES, INC.

Mr. KURZWEIL. Thank you, Chairman Boehlert and distinguished Members of the House Science Committee. I greatly appreciate this opportunity to respond to this vital issue. Chairman Boehlert, you just mentioned that the truth of nanotechnology will be somewhere in between great benefit and great danger. I would say that we will ultimately see both great promise and some peril. I think with the right strategies, we can manage the peril.

Our rapidly growing ability to manipulate matter and energy at ever smaller scales promises to transform virtually every sector of society, including health, medicine, manufacturing, electronics and computers, energy, travel, and defense. There will be increasing overlap between nanotechnology and other technologies and increasing influence, such as biotech and artificial intelligence. As with any other technological transformation, we will be faced with deeply intertwined promise and peril.

For the past two decades, I have been studying technology trends. I have a team of researchers who assist me in gathering critical measures of technology in different areas. I have been developing mathematical models of how technology evolves. Technologies, especially those related to information, develop at an exponential pace, generally doubling in capability and price performance every year. And this goes beyond just computers or Moore's Law. It includes, really, any information-based technology, and ultimately, nanotech will be like that. It includes communication, DNA sequencing, brain scanning, brain reverse engineering, the size and scope of human knowledge, and of particular relevance, the size of technology is inexorably shrinking.

According to my models, both electronic and mechanical technologies are shrinking at a rate of 5.6 per linear dimension per decade, so at this rate, most of technology will be nanotechnology by the 2020's. The golden age of nanotech, therefore, is a couple of decades away. And this era will bring us the ability to essentially convert information into physical products. We are already placing devices with narrow intelligence into our bodies for diagnostic and therapeutic purposes. With the advent of nanotechnology, we will be able to keep our bodies and brains in a healthy optimal state more or less indefinitely. We will have technologies to reverse environmental pollution. Nanotechnology and related advanced technologies of the 2020's will bring us the opportunity to overcome age-old problems, including pollution, poverty, disease, and aging.

We hear increasingly strident voices that object to the intermingling of the so-called natural world with the products of our technology. And this increasing intimacy of our human lives with our technology is not a new story. Had it not been for the technological advances of the past two centuries, most of us here today wouldn't be here today. Human life expectancy was 37 years in 1800. We are immeasurably better off as a result of technology, but there is still a lot of suffering in the world to overcome. We have a moral imperative, therefore, to continue the pursuit of knowledge and advanced technologies, such as nanotechnology.

There is also an economic imperative. Nanotechnology is not a single field of study that we can simply relinquish as others have suggested. Nanotechnology is advancing on hundreds of fronts, and it is an extremely diverse activity. We can't relinquish its pursuit without essentially relinquishing all of technology.

But technology has always been a double-edged sword. That will certainly be true of nanotechnology as you pointed out in your opening statement. We see that duality today in biotechnology. The same techniques that could save millions of lives from cancer may also empower a bioterrorist.

A lot of attention has been paid to the problem of self-replicating nanotechnology entities. You referred to it as "gray goo." I discuss in my written testimony steps we can take now and in the future to diminish these dangers, but the primary point I would like to make is that we are going to have no choice but to confront the challenge of guiding nanotechnology in a constructive direction. Any broad attempt to relinquish nanotechnology, as some have suggested, will only push it underground, which would interfere with the benefits, while actually making the dangers worse.

As a test case, let me bring up an example. We can take a small measure of comfort from how we have dealt with one recent technological challenge. There exists today a new form of fully non-biological, self-replicating entity that didn't exist just a few decades ago, the computer or software virus. When this form of destructive intruder first appeared, strong concerns were voiced that as they became more sophisticated, software pathogens had the potential to destroy the computer network medium they live in yet the immune system that has evolved in response to this challenge has been largely effective. No one would suggest we do away with the Internet because of software viruses. Our response has been effective and successful, although there remain, and always will remain a concern, the danger remains at a nuisance level. Keep in mind, this success is in an industry in which there is no regulation, no certification for practitioners.

The near-term applications of nanotechnology, such as nanoparticles, are far more limited in their benefits as well as far more benign in their potential dangers. The voices that are expressing concern about nanotechnology are the same voices that have expressed undue levels of concern about genetically modified organisms. The effects of anti-technology stance that has been reflected in the GMO controversy will not be helpful in constructively balancing the benefits and risks of nanoparticle technology and nanotechnology in general as we move forward.

Thank you very much.

[The prepared statement of Mr. Kurzweil follows:]

PREPARED STATEMENT OF RAYMOND KURZWEIL

SUMMARY OF TESTIMONY:

The size of technology is itself inexorably shrinking. According to my models, both electronic and mechanical technologies are shrinking at a rate of 5.6 per linear dimension per decade. At this rate, most of technology will be "nanotechnology" by the 2020s.

We are immeasurably better off as a result of technology, but there is still a lot of suffering in the world to overcome. We have a moral imperative, therefore, to continue the pursuit of knowledge and advanced technologies, such as nanotechnology, that can continue to overcome human affliction. There is also an economic imperative to continue due to the pervasive acceleration of technology, including miniaturization, in the competitive economy.

Nanotechnology is not a separate field of study that we can simply relinquish. We will have no choice but to confront the challenge of guiding nanotechnology in a constructive direction. There are strategies we can deploy, but there will need to be continual development of defensive strategies.

We can take some level of comfort from our relative success in dealing with one new form of fully non-biological, self-replicating pathogen: the software virus.

The most immediate danger is not self-replicating nanotechnology, but rather self-replicating biotechnology. We need to place a much higher priority on developing vitally needed defensive technologies such as antiviral medications. Keep in mind that a bioterrorist does not need to put his "innovations" through the FDA.

Any broad attempt to relinquish nanotechnology will only push it underground, which would interfere with the benefits while actually making the dangers worse.

Existing regulations on the safety of foods, drugs, and other materials in the environment are sufficient to deal with the near-term applications of nanotechnology, such as nanoparticles.

Full Verbal Testimony:

In my brief verbal remarks, I only have time to summarize my Chairman Boehlert, distinguished members of the U.S. House of Representatives Committee on Science, and other distinguished guests, I appreciate this opportunity to respond to your questions and concerns on the vital issue of the societal implications of nanotechnology. Our rapidly growing ability to manipulate matter and energy at ever smaller scales promises to transform virtually every sector of society, including health and medicine, manufacturing, electronics and computers, energy, travel, and defense. There will be increasing overlap between nanotechnology and other technologies of increasing influence, such as biotechnology and artificial intelligence. As with any other technological transformation, we will be faced with deeply intertwined promise and peril.

In my brief verbal remarks, I only have time to summarize my conclusions on this complex subject, and I am providing the Committee with an expanded written response that attempts to explain the reasoning behind my views.

Eric Drexler's 1986 thesis developed the concept of building molecule-scale devices using molecular assemblers that would precisely guide chemical reactions. Without going through the history of the controversy surrounding feasibility, it is fair to say that the consensus today is that nano-assembly is indeed feasible, although the most dramatic capabilities are still a couple of decades away.

The concept of nanotechnology today has been expanded to include essentially any technology where the key features are measured in a modest number of nanometers (under 100 by some definitions). By this standard, contemporary electronics has already passed this threshold.

For the past two decades, I have studied technology trends, along with a team of researchers who have assisted me in gathering critical measures of technology in different areas, and I have been developing mathematical models of how technology evolves. Several conclusions from this study have a direct bearing on the issues before this hearing. Technologies, particularly those related to information, develop at an exponential pace, generally doubling in capability and price-performance every year. This observation includes the power of computation, communication—both wired and wireless, DNA sequencing, brain scanning, brain reverse engineering, and the size and scope of human knowledge in general. Of particular relevance to this hearing, the size of technology is itself inexorably shrinking. According to my models, both electronic and mechanical technologies are shrinking at a rate of 5.6 per linear dimension per decade. At this rate, most of technology will be "nanotechnology" by the 2020s.

The golden age of nanotechnology is, therefore, a couple of decades away. This era will bring us the ability to essentially convert software, i.e., information, directly into physical products. We will be able to produce virtually any product for pennies per pound. Computers will have greater computational capacity than the human brain, and we will be completing the reverse engineering of the human brain to reveal the software design of human intelligence. We are already placing devices with narrow intelligence in our bodies for diagnostic and therapeutic purposes. With the advent of nanotechnology, we will be able to keep our bodies and brains in a healthy, optimal state indefinitely. We will have technologies to reverse environmental pollution. Nanotechnology and related advanced technologies of the 2020s will bring us the opportunity to overcome age-old problems, including pollution, poverty, disease, and aging.

We hear increasingly strident voices that object to the intermingling of the so-called natural world with the products of our technology. The increasing intimacy of our human lives with our technology is not a new story, and I would remind the committee that had it not been for the technological advances of the past two centuries, most of us here today would not be here today. Human life expectancy was 37 years in 1800. Most humans at that time lived lives dominated by poverty, intense labor, disease, and misfortune. We are immeasurably better off as a result of technology, but there is still a lot of suffering in the world to overcome. We have a moral imperative, therefore, to continue the pursuit of knowledge and of advanced technologies that can continue to overcome human affliction.

There is also an economic imperative to continue. Nanotechnology is not a single field of study that we can simply relinquish, as suggested by Bill Joy's essay, "Why the Future Doesn't Need Us." Nanotechnology is advancing on hundreds of fronts, and is an extremely diverse activity. We cannot relinquish its pursuit without essentially relinquishing all of technology, which would require a Brave New World totalitarian scenario, which is inconsistent with the values of our society.

Technology has always been a double-edged sword, and that is certainly true of nanotechnology. The same technology that promises to advance human health and wealth also has the potential for destructive applications. We can see that duality today in biotechnology. The same techniques that could save millions of lives from cancer and disease may also empower a bioterrorist to create a bioengineered pathogen.

A lot of attention has been paid to the problem of self-replicating nanotechnology entities that could essentially form a nonbiological cancer that would threaten the planet. I discuss in my written testimony steps we can take now and in the future to ameliorate these dangers. However, the primary point I would like to make is that we will have no choice but to confront the challenge of guiding nanotechnology in a constructive direction. Any broad attempt to relinquish nanotechnology will only push it underground, which would interfere with the benefits while actually making the dangers worse.

As a test case, we can take a small measure of comfort from how we have dealt with one recent technological challenge. There exists today a new form of fully nonbiological self-replicating entity that didn't exist just a few decades ago: the computer virus. When this form of destructive intruder first appeared, strong concerns were voiced that as they became more sophisticated, software pathogens had the potential to destroy the computer network medium they live in. Yet the "immune system" that has evolved in response to this challenge has been largely effective. Although destructive self-replicating software entities do cause damage from time to time, the injury is but a small fraction of the benefit we receive from the computers and communication links that harbor them. No one would suggest we do away with computers, local area networks, and the Internet because of software viruses.

One might counter that computer viruses do not have the lethal potential of biological viruses or of destructive nanotechnology. This is not always the case: we rely on software to monitor patients in critical care units, to fly and land airplanes, to guide intelligent weapons in our current campaign in Iraq, and other "mission critical" tasks. To the extent that this is true, however, this observation only strengthens my argument. The fact that computer viruses are not usually deadly to humans only means that more people are willing to create and release them. It also means that our response to the danger is that much less intense. Conversely, when it comes to self-replicating entities that are potentially lethal on a large scale, our response on all levels will be vastly more serious, as we have seen since 9–11.

I would describe our response to software pathogens as effective and successful. Although they remain (and always will remain) a concern, the danger remains at a nuisance level. Keep in mind that this success is in an industry in which there is no regulation, and no certification for practitioners. This largely unregulated industry is also enormously productive. One could argue that it has contributed more to our technological and economic progress than any other enterprise in human history.

Some of the concerns that have been raised, such as Bill Joy's article, are effective because they paint a picture of future dangers as if they were released on today's unprepared world. The reality is that the sophistication and power of our defensive technologies and knowledge will grow along with the dangers.

The challenge most immediately in front of us is not self-replicating nanotechnology, but rather self-replicating biotechnology. The next two decades will be the golden age of biotechnology, whereas the comparable era for nanotechnology will follow in the 2020s and beyond. We are now in the early stages of a transforming technology based on the intersection of biology and information science. We are learning the "software" methods of life and disease processes. By reprogramming the information processes that lead to and encourage disease and aging, we will have the ability to overcome these afflictions. However, the same knowledge can also empower a terrorist to create a bioengineered pathogen.

As we compare the success we have had in controlling engineered software viruses to the coming challenge of controlling engineered biological viruses, we are struck with one salient difference. As I noted, the software industry is almost completely unregulated. The same is obviously not the case for biotechnology. *A bioterrorist does not need to put his "innovations" through the FDA.* However, we do require the scientists developing the defensive technologies to follow the existing regulations, which slow down the innovation process at every step. Moreover, it is impossible, under existing regulations and ethical standards, to test defenses to bioterrorist agents on humans. There is already extensive discussion to modify these regulations to allow for animal models and simulations to replace infeasible human trials. This will be necessary, but I believe we will need to go beyond these steps to accelerate the development of vitally needed defensive technologies.

With the human genome project, 3 to 5 percent of the budgets were devoted to the ethical, legal, and social implications (ELSI) of the technology. A similar commitment for nanotechnology would be appropriate and constructive.

Near-term applications of nanotechnology are far more limited in their benefits as well as more benign in their potential dangers. These include developments in the materials area involving the addition of particles with multi-nanometer features to plastics, textiles, and other products. These have perhaps the greatest potential in the area of pharmaceutical development by allowing new strategies for highly targeted drugs that perform their intended function and reach the appropriate tissues, while minimizing side effects. This development is not qualitatively different than what we have been doing for decades in that many new materials involve constituent particles that are novel and of a similar physical scale. The emerging nanoparticle technology provides more precise control, but the idea of introducing new nonbiological materials into the environment is hardly a new phenomenon. We cannot say a priori that all nanoengineered particles are safe, nor would it be appropriate to deem them necessarily unsafe. Environmental tests thus far have not shown reasons for undue concern, and it is my view that existing regulations on the safety of foods, drugs, and other materials in the environment are sufficient to deal with these near-term applications.

The voices that are expressing concern about nanotechnology are the same voices that have expressed undue levels of concern about genetically modified organisms. As with nanoparticles, GMOs are neither inherently safe nor unsafe, and reasonable levels of regulation for safety are appropriate. However, none of the dire warnings about GMOs have come to pass. Already, African nations, such as Zambia and Zimbabwe, have rejected vitally needed food aid under pressure from European anti-GMO activists. The reflexive anti-technology stance that has been reflected in the GMO controversy will not be helpful in balancing the benefits and risks of nanoparticle technology.

In summary, I believe that existing regulatory mechanisms are sufficient to handle near-term applications of nanotechnology. As for the long-term, we need to appreciate that a myriad of nanoscale technologies are inevitable. The current examinations and dialogues on achieving the promise while ameliorating the peril are appropriate and will deserve sharply increased attention as we get closer to realizing these revolutionary technologies.

Written Testimony

I am pleased to provide a more detailed written response to the issues raised by the Committee. In this written portion of my response, I address the following issues:

- **Models of Technology Trends:** A discussion of why nanotechnology and related advanced technologies are inevitable. The underlying technologies are deeply integrated into our society and are advancing on many diverse fronts.
- **A Small Sample of Examples of True Nanotechnology:** A few of the implications of nanotechnology two to three decades from now.
- **The Economic Imperatives of the Law of Accelerating Returns:** The exponential advance of technology, including the accelerating miniaturization of technology, is driven by economic imperative, and, in turn, has a pervasive impact on the economy.
- **The Deeply Intertwined Promise and Peril of Nanotechnology and Related Advanced Technologies:** Technology is inherently a doubled-edged sword, and we will need to adopt strategies to encourage the benefits while ameliorating the risks. Relinquishing broad areas of technology, as has been proposed, is not feasible and attempts to do so will only drive technology development underground, which will exacerbate the dangers.

Models of Technology Trends

A diverse technology such as nanotechnology progresses on many fronts and is comprised of hundreds of small steps forward, each benign in itself. An examination of these trends shows that technology in which the key features are measured in a small number of nanometers is inevitable. I hereby provide some examples of my study of technology trends.

The motivation for this study came from my interest in inventing. As an inventor in the 1970s, I came to realize that my inventions needed to make sense in terms of the enabling technologies and market forces that would exist when the invention was introduced, which would represent a very different world than when it was conceived. I began to develop models of how distinct technologies—electronics, communications, computer processors, memory, magnetic storage, and the size of technology—developed and how these changes rippled through markets and ultimately our social institutions. I realized that most inventions fail not because they never work, but because their timing is wrong. Inventing is a lot like surfing, you have to anticipate and catch the wave at just the right moment.

In the 1980s, my interest in technology trends and implications took on a life of its own, and I began to use my models of technology trends to project and anticipate the technologies of future times, such as the year 2000, 2010, 2020, and beyond. This enabled me to invent with the capabilities of the future. In the late 1980s, I wrote my first book, *The Age of Intelligent Machines,* which ended with the specter of machine intelligence becoming indistinguishable from its human progenitors. This book included hundreds of predictions about the 1990s and early 2000 years, and my track record of prediction has held up well.

During the 1990s I gathered empirical data on the apparent acceleration of all information-related technologies and sought to refine the mathematical models underlying these observations. In *The Age of Spiritual Machines* (ASM), which I wrote in 1998, I introduced refined models of technology, and a theory I called "the law of accelerating returns," which explained why technology evolves in an exponential fashion.

The Intuitive Linear View Versus the Historical Exponential View

The future is widely misunderstood. Our forebears expected the future to be pretty much like their present, which had been pretty much like their past. Although exponential trends did exist a thousand years ago, they were at that very early stage where an exponential trend is so flat and so slow that it looks like no trend at all. So their lack of expectations was largely fulfilled. Today, in accordance with the common wisdom, everyone expects continuous technological progress and the social repercussions that follow. But the future will nonetheless be far more surprising than most observers realize because few have truly internalized the implications of the fact that the rate of change itself is accelerating.

Most long-range forecasts of technical feasibility in future time periods dramatically underestimate the power of future developments because they are based on what I call the "intuitive linear" view of history rather than the "historical exponential view." To express this another way, it is not the case that we will experience a hundred years of progress in the twenty-first century; rather we will witness on the order of twenty thousand years of progress (at *today's* rate of progress, that is).

When people think of a future period, they intuitively assume that the current rate of progress will continue for future periods. Even for those who have been around long enough to experience how the pace increases over time, an unexamined intuition nonetheless provides the impression that progress changes at the rate that we have experienced recently. From the mathematician's perspective, a primary reason for this is that an exponential curve approximates a straight line when viewed for a brief duration. It is typical, therefore, that even sophisticated commentators, when considering the future, extrapolate the current pace of change over the next 10 years or 100 years to determine their expectations. This is why I call this way of looking at the future the "intuitive linear" view.

But a serious assessment of the history of technology shows that technological change is exponential. In exponential growth, we find that a key measurement such as computational power is multiplied by a constant factor for each unit of time (e.g., doubling every year) rather than just being added to incrementally. Exponential growth is a feature of any evolutionary process, of which technology is a primary example. One can examine the data in different ways, on different time scales, and for a wide variety of technologies ranging from electronic to biological, as well as social implications ranging from the size of the economy to human life span, and the acceleration of progress and growth applies. Indeed, we find not just simple exponential growth, but "double" exponential growth, meaning that the rate of exponential growth is itself growing exponentially. These observations do not rely merely on an assumption of the continuation of Moore's law (i.e., the exponential shrinking of transistor sizes on an integrated circuit), but is based on a rich model of diverse technological processes. What it clearly shows is that technology, particularly the pace of technological change, advances (at least) exponentially, not linearly, and has been doing so since the advent of technology, indeed since the advent of evolution on Earth.

Many scientists and engineers have what my colleague Lucas Hendrich calls "engineer's pessimism." Often an engineer or scientist who is so immersed in the difficulties and intricate details of a contemporary challenge fails to appreciate the ultimate long-term implications of their own work, and, in particular, the larger field of work that they operate in. Consider the biochemists in 1985 who were skeptical of the announcement of the goal of transcribing the entire genome in a mere 15 years. These scientists had just spent an entire year transcribing a mere one ten-thousandth of the genome, so even with reasonable anticipated advances, it seemed to them like it would be hundreds of years, if not longer, before the entire genome could be sequenced. Or consider the skepticism expressed in the mid 1980s that the Internet would ever be a significant phenomenon, given that it included only tens of thousands of nodes. The fact that the number of nodes was doubling every year and there were, therefore, likely to be tens of millions of nodes ten years later was not appreciated by those who struggled with "state-of-the-art" technology in 1985, which permitted adding only a few thousand nodes throughout the world in a year.

I emphasize this point because it is the most important failure that would-be prognosticators make in considering future trends. The vast majority of technology forecasts and forecasters ignore altogether this "historical exponential view" of technological progress. Indeed, almost everyone I meet has a linear view of the future. That is why people tend to over estimate what can be achieved in the short-term (because we tend to leave out necessary details), but underestimate what can be achieved in the long-term (because the exponential growth is ignored).

The Law of Accelerating Returns

The ongoing acceleration of technology is the implication and inevitable result of what I call the "law of accelerating returns," which describes the acceleration of the pace and the exponential growth of the products of an evolutionary process. This includes technology, particularly information-bearing technologies, such as computation. More specifically, the law of accelerating returns states the following:

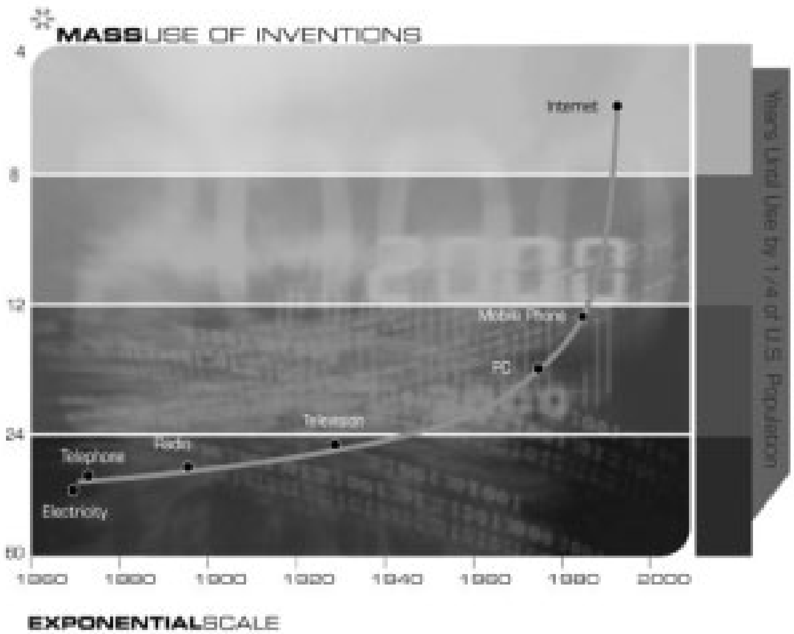
- Evolution applies positive feedback in that the more capable methods resulting from one stage of evolutionary progress are used to create the next stage. As a result, the rate of progress of an evolutionary process increases exponentially over time. Over time, the "order" of the information embedded in the evolutionary process (i.e., the measure of how well the information fits a purpose, which in evolution is survival) increases.
- A correlate of the above observation is that the "returns" of an evolutionary process (e.g., the speed, cost-effectiveness, or overall "power" of a process) increase exponentially over time.
- In another positive feedback loop, as a particular evolutionary process (e.g., computation) becomes more effective (e.g., cost effective), greater resources are deployed towards the further progress of that process. This results in a second level of exponential growth (i.e., the rate of exponential growth itself grows exponentially).
- Biological evolution is one such evolutionary process.

- Technological evolution is another such evolutionary process. Indeed, the emergence of the first technology-creating species resulted in the new evolutionary process of technology. Therefore, technological evolution is an out growth of—and a continuation of—biological evolution.
- A specific paradigm (a method or approach to solving a problem, e.g., shrinking transistors on an integrated circuit as an approach to making more powerful computers) provides exponential growth until the method exhausts its potential. When this happens, a paradigm shift (a fundamental change in the approach) occurs, which enables exponential growth to continue.
- Each paradigm follows an "S-curve," which consists of slow growth (the early phase of exponential growth), followed by rapid growth (the late, explosive phase of exponential growth), followed by a leveling off as the particular paradigm matures.
- During this third or maturing phase in the life cycle of a paradigm, pressure builds for the next paradigm shift.
- When the paradigm shift occurs, the process begins a new S-curve.
- Thus the acceleration of the overall evolutionary process proceeds as a sequence of S-curves, and the overall exponential growth consists of this cascade of S-curves.
- The resources underlying the exponential growth of an evolutionary process are relatively unbounded.
- One resource is the (ever-growing) order of the evolutionary process itself. Each stage of evolution provides more powerful tools for the next. In biological evolution, the advent of DNA allowed more powerful and faster evolutionary "experiments." Later, setting the "designs" of animal body plans during the Cambrian explosion allowed rapid evolutionary development of other body organs, such as the brain. Or to take a more recent example, the advent of computer-assisted design tools allows rapid development of the next generation of computers.
- The other required resource is the "chaos" of the environment in which the evolutionary process takes place and which provides the options for further diversity. In biological evolution, diversity enters the process in the form of mutations and ever-changing environmental conditions, including cosmological disasters (e.g., asteroids hitting the Earth). In technological evolution, human ingenuity combined with ever changing market conditions keep the process of innovation going.

If we apply these principles at the highest level of evolution on Earth, the first step, the creation of cells, introduced the paradigm of biology. The subsequent emergence of DNA provided a digital method to record the results of evolutionary experiments. Then, the evolution of a species that combined rational thought with an opposable appendage (the thumb) caused a fundamental paradigm shift from biology to technology. The upcoming primary paradigm shift will be from biological thinking to a hybrid combining biological and nonbiological thinking. This hybrid will include "biologically inspired" processes resulting from the reverse engineering of biological brains.

If we examine the timing of these steps, we see that the process has continuously accelerated. The evolution of life forms required billions of years for the first steps (e.g., primitive cells); later on progress accelerated. During the Cambrian explosion, major paradigm shifts took only tens of millions of years. Later on, Humanoids developed over a period of millions of years, and Homo sapiens over a period of only hundreds of thousands of years.

With the advent of a technology-creating species, the exponential pace became too fast for evolution through DNA-guided protein synthesis and moved on to human-created technology. Technology goes beyond mere tool making; it is a process of creating ever more powerful technology using the tools from the previous round of innovation, and is, thereby, an evolutionary process. The first technological steps—sharp edges, fire, the wheel—took tens of thousands of years. For people living in this era, there was little noticeable technological change in even a thousand years. By 1000 AD, progress was much faster and a paradigm shift required only a century or two. In the nineteenth century, we saw more technological change than in the nine centuries preceding it. Then in the first twenty years of the twentieth century, we saw more advancement than in all of the nineteenth century. Now, paradigm shifts occur in only a few years time. The World Wide Web did not exist in anything like its present form just a few years ago; it didn't exist at all a decade ago.



The paradigm shift rate (i.e., the overall rate of technical progress) is currently doubling (approximately) every decade; that is, paradigm shift times are halving every decade (and the rate of acceleration is itself growing exponentially). So, the technological progress in the twenty-first century will be equivalent to what would require (in the linear view) on the order of 200 centuries. In contrast, the twentieth century saw only about 20 years of progress (again at today's rate of progress) since we have been speeding up to current rates. So the twenty-first century will see about a thousand times greater technological change than its predecessor.

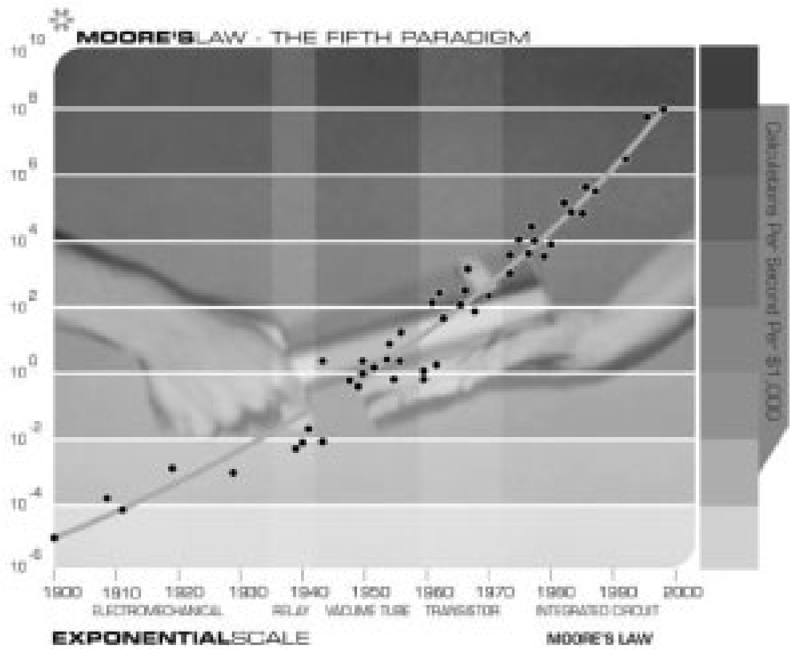
Moore's Law and Beyond

There is a wide range of technologies that are subject to the law of accelerating returns. The exponential trend that has gained the greatest public recognition has become known as "Moore's Law." Gordon Moore, one of the inventors of integrated circuits, and then Chairman of Intel, noted in the mid-1970s that we could squeeze twice as many transistors on an integrated circuit every 24 months. Given that the electrons have less distance to travel, the circuits also run twice as fast, providing an overall quadrupling of computational power.

However, the exponential growth of computing is much broader than Moore's Law.

If we plot the speed (in instructions per second) per $1000 (in constant dollars) of 49 famous calculators and computers spanning the entire twentieth century, we note that there were four completely different paradigms that provided exponential growth in the price-performance of computing before the integrated circuits were invented. Therefore, Moore's Law was not the first, but the fifth paradigm to exponentially grow the power of computation. And it won't be the last. When Moore's Law reaches the end of its S-curve, now expected before 2020, the exponential growth will continue with three-dimensional molecular computing, a prime example of the application of nanotechnology, which will constitute the sixth paradigm.

When I suggested in my book *The Age of Spiritual Machines,* published in 1999, that three-dimensional molecular computing, particularly an approach based on using carbon nanotubes, would become the dominant computing hardware technology in the teen years of this century, that was considered a radical notion. There has been so much progress in the past four years, with literally dozens of major milestones having been achieved, that this expectation is now a mainstream view.



Moore's Law Was Not the First, but the Fifth Paradigm
To Provide Exponential Growth of Computing
Each time one paradigm runs out of steam, another picks up the pace

The exponential growth of computing is a marvelous quantitative example of the exponentially growing returns from an evolutionary process. We can express the exponential growth of computing in terms of an accelerating pace: it took 90 years to achieve the first MIPS (million instructions per second) per thousand dollars; now we add one MIPS per thousand dollars every day.

Moore's Law narrowly refers to the number of transistors on an integrated circuit of fixed size, and sometimes has been expressed even more narrowly in terms of transistor feature size. But rather than feature size (which is only one contributing factor), or even number of transistors, I think the most appropriate measure to track is computational speed per unit cost. This takes into account many levels of "cleverness" (i.e., innovation, which is to say, technological evolution). In addition to all of the innovation in integrated circuits, there are multiple layers of innovation in computer design, e.g., pipelining, parallel processing, instruction look-ahead, instruction and memory caching, and many others.

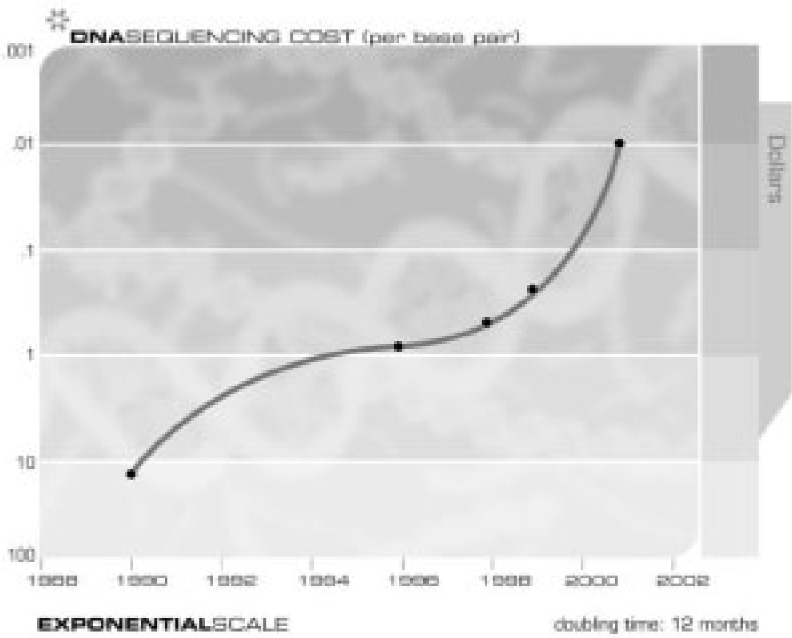
The human brain uses a very inefficient electrochemical digital-controlled analog computational process. The bulk of the calculations are done in the interneuronal connections at a speed of only about 200 calculations per second (in each connection), which is about ten million times slower than contemporary electronic circuits. But the brain gains its prodigious powers from its extremely parallel organization *in three dimensions.* There are many technologies in the wings that build circuitry in three dimensions. Nanotubes, an example of nanotechnology, which is already working in laboratories, build circuits from pentagonal arrays of carbon atoms. One cubic inch of nanotube circuitry would be a million times more powerful than the human brain. There are more than enough new computing technologies now being researched, including three-dimensional silicon chips, optical and silicon spin computing, crystalline computing, DNA computing, and quantum computing, to keep the law of accelerating returns as applied to computation going for a long time.

As I discussed above, it is important to distinguish between the "S" curve (an "S" stretched to the right, comprising very slow, virtually unnoticeable growth—followed by very rapid growth—followed by a flattening out as the process approaches an asymptote) that is characteristic of any specific technological paradigm and the continuing exponential growth that is characteristic of the ongoing evolutionary process of technology. Specific paradigms, such as Moore's Law, do ultimately reach levels at which exponential growth is no longer feasible. That is why Moore's Law is an S-curve. But the growth of computation is an ongoing exponential (at least until we "saturate" the Universe with the intelligence of our human-machine civilization, but that will not be a limit in this coming century). In accordance with the law of accelerating returns, paradigm shift, also called innovation, turns the S-curve of any specific paradigm into a continuing exponential. A new paradigm (e.g., three-dimensional circuits) takes over when the old paradigm approaches its natural limit, which has already happened at least four times in the history of computation. This difference also distinguishes the tool making of non-human species, in which the mastery of a tool-making (or using) skill by each animal is characterized by an abruptly ending S shaped learning curve, versus human-created technology, which has followed an exponential pattern of growth and acceleration since its inception.

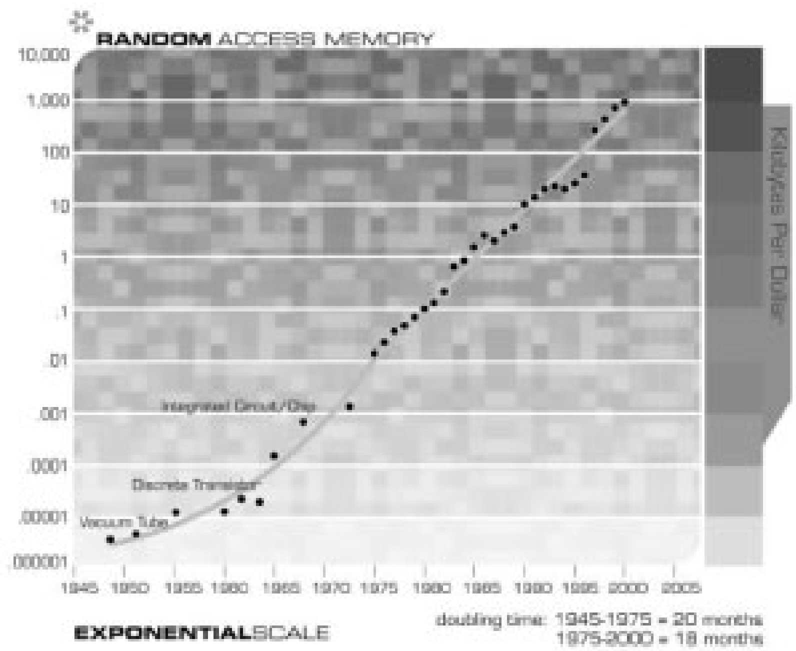
DNA Sequencing, Memory, Communications, the Internet, and Miniaturization

This "law of accelerating returns" applies to all of technology, indeed to any true evolutionary process, and can be measured with remarkable precision in information-based technologies. There are a great many examples of the exponential growth implied by the law of accelerating returns in technologies, as varied as DNA sequencing, communication speeds, brain scanning, electronics of all kinds, and even in the rapidly shrinking size of technology, which is directly relevant to the discussion at this hearing. The future nanotechnology age results not from the exponential explosion of computation alone, but rather from the interplay and myriad synergies that will result from manifold intertwined technological revolutions. Also, keep in mind that every point on the exponential growth curves underlying these panoply of technologies (see the graphs below) represents an intense human drama of innovation and competition. It is remarkable therefore that these chaotic processes result in such smooth and predictable exponential trends.

As I noted above, when the human genome scan started fourteen years ago, critics pointed out that given the speed with which the genome could then be scanned, it would take thousands of years to finish the project. Yet the fifteen year project was nonetheless completed slightly ahead of schedule.

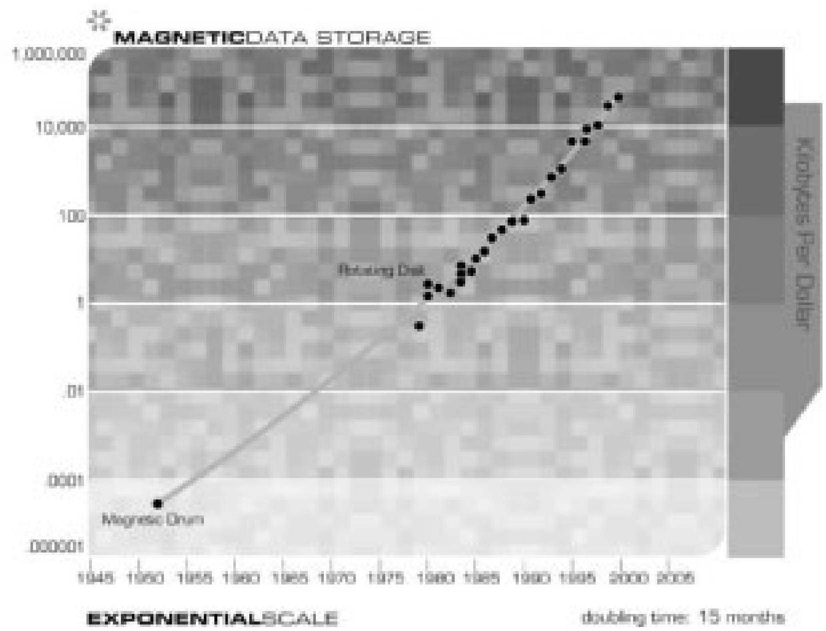


Of course, we expect to see exponential growth in electronic memories such as RAM.

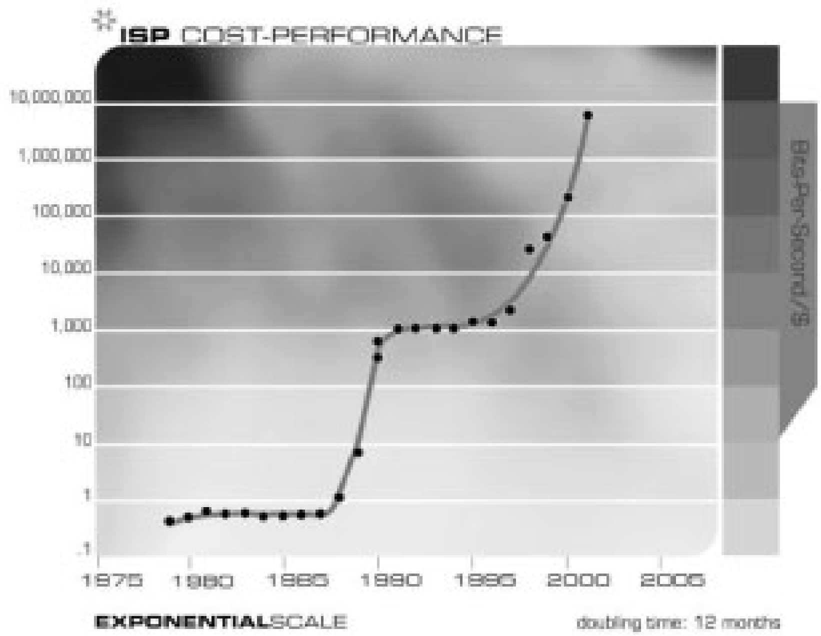


Notice How Exponential Growth Continued
through Paradigm Shifts from Vacuum Tubes
to Discrete Transistors to Integrated Circuits

However, growth in magnetic memory is not primarily a matter of Moore’s law, but includes advances in mechanical and electromagnetic systems.



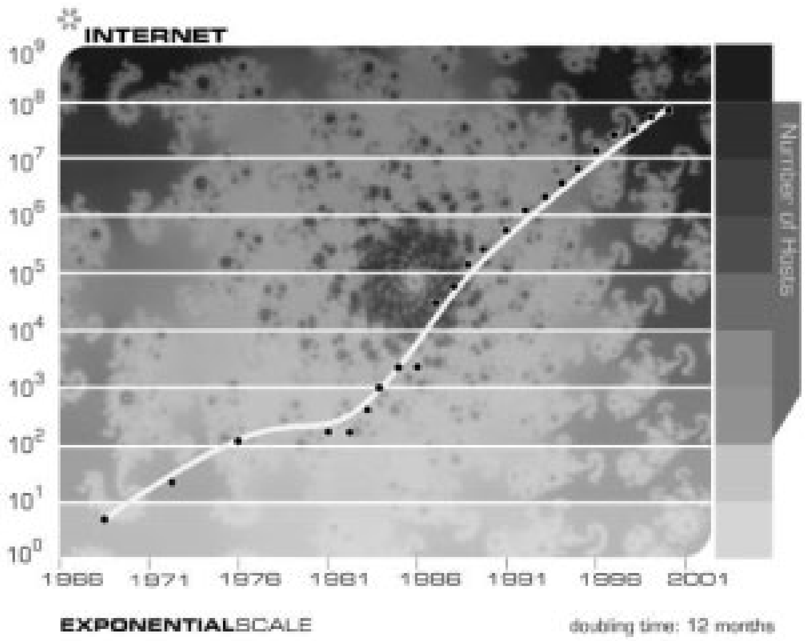
Exponential growth in communications technology has been even more explosive than in computation and is no less significant in its implications. Again, this progression involves far more than just shrinking transistors on an integrated circuit, but includes accelerating advances in fiber optics, optical switching, electromagnetic technologies, and others.

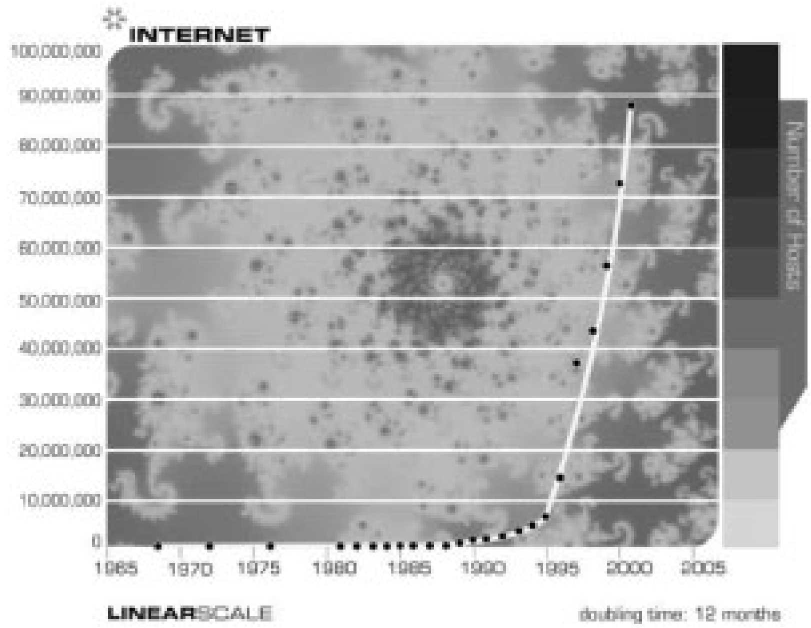


Notice Cascade of "S" Curves

Note that in the above chart we can actually see the progression of "S" curves: the acceleration fostered by a new paradigm, followed by a leveling off as the paradigm runs out of steam, followed by renewed acceleration through paradigm shift.

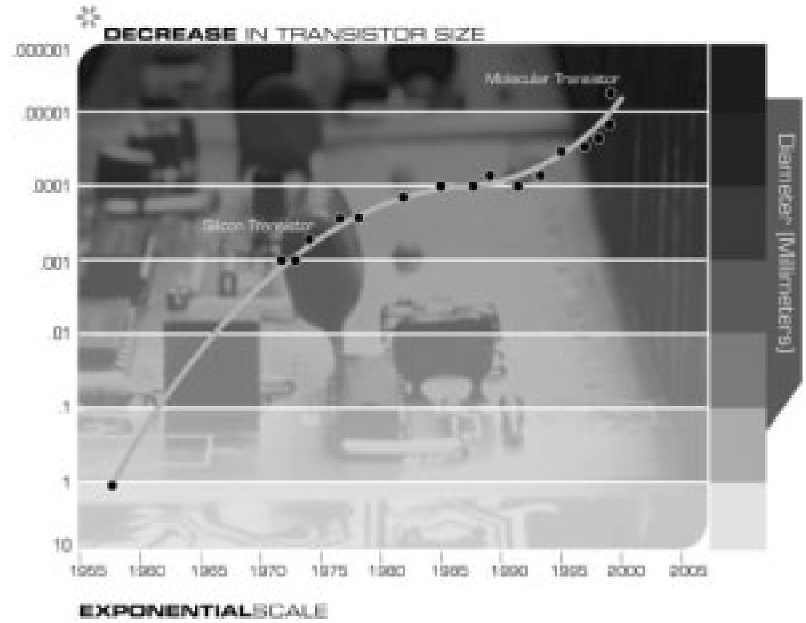
The following two charts show the overall growth of the Internet based on the number of hosts (server computers). These two charts plot the same data, but one is on an exponential axis and the other is linear. As I pointed out earlier, whereas technology progresses in the exponential domain, we experience it in the linear domain. So from the perspective of most observers, nothing was happening until the mid 1990s when seemingly out of nowhere, the World Wide Web and e-mail exploded into view. But the emergence of the Internet into a worldwide phenomenon was readily predictable much earlier by examining the exponential trend data.

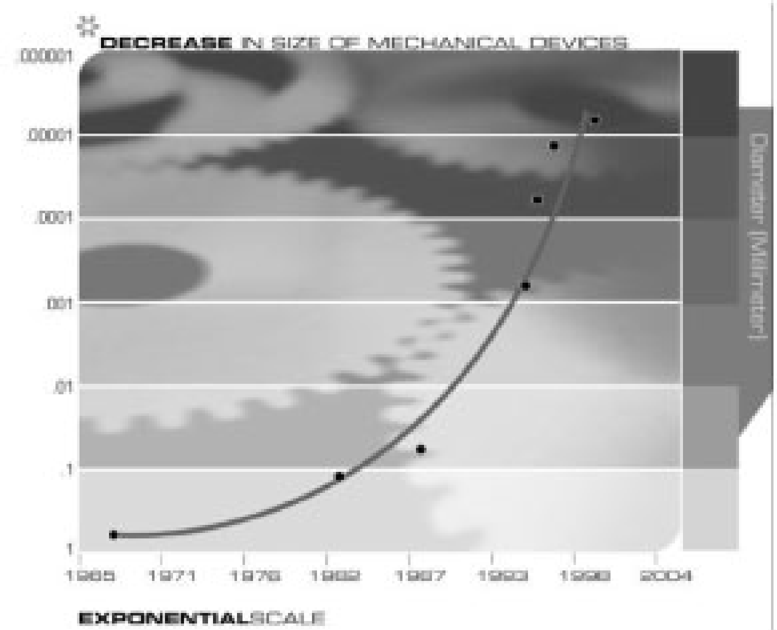

INTERNET
10^9
10^8
10^7
10^6
10^5
10^4
10^3
10^2
10^1
10^0
1966
1971
1976
1981
1986
1991
1996
2001
Number of Hosts
EXPONENTIALSCALE
doubling time: 12 months



Notice how the explosion of the Internet appears to be a surprise from the Linear Chart, but was perfectly predictable from the Exponential Chart

The most relevant trend to this hearing, and one that will have profound implications for the twenty-first century is the pervasive trend towards making things smaller, i.e., miniaturization. The salient implementation sizes of a broad range of technologies, both electronic and mechanical, are shrinking, also at a double-exponential rate. At present, we are shrinking technology by a factor of approximately 5.6 per linear dimension per decade.


DECREASE IN TRANSISTOR SIZE
.000001
.00001
.0001
.001
.01
.1
1
10
Molecular Transistor
Silicon Transistor
Diameter [Millimeters]
1955
1960
1965
1970
1975
1980
1985
1990
1995
2000
2005
EXPONENTIALSCALE


DECREASE IN SIZE OF MECHANICAL DEVICES
.000001
.00001
.0001
.001
.01
.1
1
Diameter [Millimeter]
1965
1971
1976
1982
1987
1993
1998
2004
EXPONENTIALSCALE

A Small Sample of Examples of True Nanotechnology

Ubiquitous nanotechnology is two to three decades away. A prime example of its application will be to deploy billions of "nanobots": small robots the size of human blood cells that can travel inside the human bloodstream. This notion is not as futuristic as it may sound in that there have already been successful animal experiments using this concept. There are already four major conferences on "BioMEMS" (Biological Micro Electronic Mechanical Systems) covering devices in the human blood stream.

Consider several examples of nanobot technology, which, based on miniaturization and cost reduction trends, will be feasible within 30 years. In addition to scanning the human brain to facilitate human brain reverse engineering, these nanobots will be able to perform a broad variety of diagnostic and therapeutic functions inside the bloodstream and human body. Robert Freitas, for example, has designed robotic replacements for human blood cells that perform hundreds or thousands of times more effectively than their biological counterparts. With Freitas' "respirocytes," (robotic red blood cells), you could do an Olympic sprint for 15 minutes without taking a breath. His robotic macrophages will be far more effective than our white blood cells at combating pathogens. His DNA repair robot would be able to repair DNA transcription errors, and even implement needed DNA changes. Although Freitas' conceptual designs are two or three decades away, there has already been substantial progress on bloodstream-based devices. For example, one scientist has cured type I Diabetes in rats with a nanoengineered device that incorporates pancreatic Islet cells. The device has seven-nanometer pores that let insulin out, but block the antibodies which destroy these cells. There are many innovative projects of this type already under way.

Clearly, nanobot technology has profound military applications, and any expectation that such uses will be "relinquished" are highly unrealistic. Already, DOD is developing "smart dust," which are tiny robots the size of insects or even smaller. Although not quite nanotechnology, millions of these devices can be dropped into enemy territory to provide highly detailed surveillance. The potential application for even smaller, nanotechnology-based devices is even greater. Want to find Saddam Hussein or Osama bin Laden? Need to locate hidden weapons of mass destruction? Billions of essentially invisible spies could monitor every square inch of enemy territory, identify every person and every weapon, and even carry out missions to destroy enemy targets. The only way for an enemy to counteract such a force is, of course, with their own nanotechnology. The point is that nanotechnology-based weapons will obsolete weapons of larger size.

In addition, nanobots will also be able to expand our experiences and our capabilities. Nanobot technology will provide fully immersive, totally convincing virtual reality in the following way. The nanobots take up positions in close physical proximity to every interneuronal connection coming from all of our senses (e.g., eyes, ears, skin). We already have the technology for electronic devices to communicate with neurons in both directions that requires no direct physical contact with the neurons. For example, scientists at the Max Planck Institute have developed "neuron transistors" that can detect the firing of a nearby neuron, or alternatively, can cause a nearby neuron to fire, or suppress it from firing. This amounts to two-way communication between neurons and the electronic-based neuron transistors. The Institute scientists demonstrated their invention by controlling the movement of a living leech from their computer. Again, the primary aspect of nanobot-based virtual reality that is not yet feasible is size and cost.

When we want to experience real reality, the nanobots just stay in position (in the capillaries) and do nothing. If we want to enter virtual reality, they suppress all of the inputs coming from the real senses, and replace them with the signals that would be appropriate for the virtual environment. You (i.e., your brain) could decide to cause your muscles and limbs to move as you normally would, but the nanobots again intercept these interneuronal signals, suppress your real limbs from moving, and instead cause your virtual limbs to move and provide the appropriate movement and reorientation in the virtual environment.

The Web will provide a panoply of virtual environments to explore. Some will be recreations of real places, others will be fanciful environments that have no "real" counterpart. Some indeed would be impossible in the physical world (perhaps, because they violate the laws of physics). We will be able to "go" to these virtual environments by ourselves, or we will meet other people there, both real people and simulated people. Of course, ultimately there won't be a clear distinction between the two.

By 2030, going to a web site will mean entering a full-immersion virtual-reality environment. In addition to encompassing all of the senses, these shared environments can include emotional overlays as the nanobots will be capable of triggering the neurological correlates of emotions, sexual pleasure, and other derivatives of our sensory experience and mental reactions.

In the same way that people today beam their lives from web cams in their bedrooms, "experience beamers" circa 2030 will beam their entire flow of sensory experiences, and if so desired, their emotions and other secondary reactions. We'll be able to plug in (by going to the appropriate web site) and experience other people's lives as in the plot concept of 'Being John Malkovich.' Particularly interesting experiences can be archived and relived at any time.

We won't need to wait until 2030 to experience shared virtual-reality environments, at least for the visual and auditory senses. Full-immersion visual-auditory environments will be available by the end of this decade, with images written directly onto our retinas by our eyeglasses and contact lenses. All of the electronics for the computation, image reconstruction, and very high bandwidth wireless connection to the Internet will be embedded in our glasses and woven into our clothing, so computers as distinct objects will disappear.

In my view, the most significant implication of the development of nanotechnology and related advanced technologies of the 21st century will be the merger of biological and nonbiological intelligence. First, it is important to point out that well before the end of the twenty-first century, thinking on nonbiological substrates will dominate. Biological thinking is stuck at 10^{26} calculations per second (for all biological human brains), and that figure will not appreciably change, even with bioengineering changes to our genome. Nonbiological intelligence, on the other hand, is growing at a double-exponential rate and will vastly exceed biological intelligence well before the middle of this century. However, in my view, this nonbiological intelligence should still be considered human as it is fully derivative of the human-machine civilization. The merger of these two worlds of intelligence is not merely a merger of biological and nonbiological thinking mediums, but more importantly one of method and organization of thinking.

One of the key ways in which the two worlds can interact will be through nanobots. Nanobot technology will be able to expand our minds in virtually any imaginable way. Our brains today are relatively fixed in design. Although we do add patterns of interneuronal connections and neurotransmitter concentrations as a normal part of the learning process, the current overall capacity of the human brain is highly constrained, restricted to a mere hundred trillion connections. Brain implants based on massively distributed intelligent nanobots will ultimately expand our memories a trillion fold, and otherwise vastly improve all of our sensory, pattern recognition, and cognitive abilities. Since the nanobots are communicating with each other over a wireless local area network, they can create any set of new neural connections, can break existing connections (by suppressing neural firing), can create new hybrid biological-nonbiological networks, as well as add vast new nonbiological networks.

Using nanobots as brain extenders is a significant improvement over the idea of surgically installed neural implants, which are beginning to be used today (e.g., ventral posterior nucleus, subthalmic nucleus, and ventral lateral thalamus neural implants to counteract Parkinson's Disease and tremors from other neurological disorders, cochlear implants, and others). Nanobots will be introduced without surgery, essentially just by injecting or even swallowing them. They can all be directed to leave, so the process is easily reversible. They are programmable, in that they can provide virtual reality one minute, and a variety of brain extensions the next. They can change their configuration, and clearly can alter their software. Perhaps most importantly, they are massively distributed and therefore can take up billions or trillions of positions throughout the brain, whereas a surgically introduced neural implant can only be placed in one or at most a few locations.

The Economic Imperatives of the Law of Accelerating Returns

It is the economic imperative of a competitive marketplace that is driving technology forward and fueling the law of accelerating returns. In turn, the law of accelerating returns is transforming economic relationships.

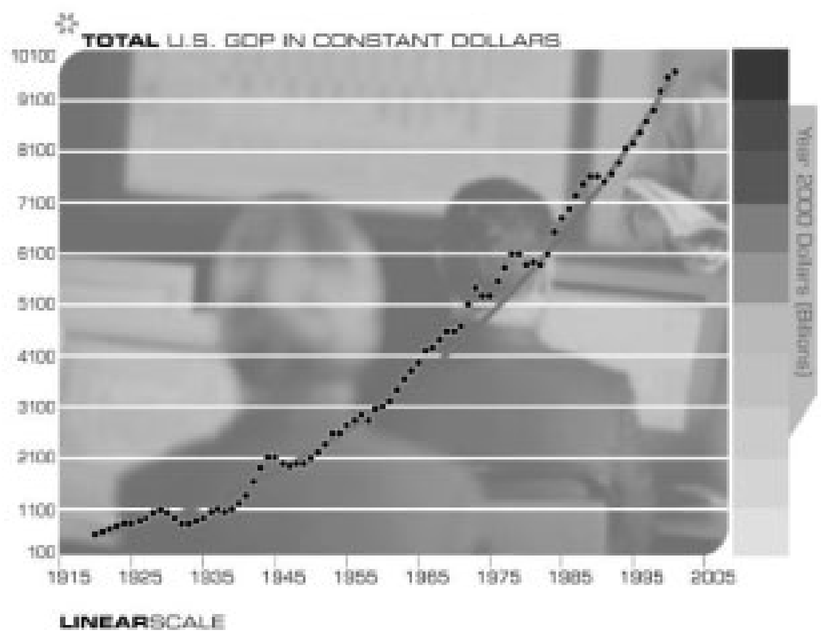
The primary force driving technology is economic imperative. We are moving towards nanoscale machines, as well as more intelligent machines, as the result of a myriad of small advances, each with their own particular economic justification.

To use one small example of many from my own experience at one of my companies (Kurzweil Applied Intelligence), whenever we came up with a slightly more intelligent version of speech recognition, the new version invariably had greater value than the earlier generation and, as a result, sales increased. It is interesting to note that in the example of speech recognition software, the three primary surviving competitors stayed very close to each other in the intelligence of their software. A few other companies that failed to do so (e.g., Speech Systems) went out of business.

At any point in time, we would be able to sell the version prior to the latest version for perhaps a quarter of the price of the current version. As for versions of our technology that were two generations old, we couldn't even give those away.

There is a vital economic imperative to create smaller and more intelligent technology. Machines that can more precisely carry out their missions have enormous value. That is why they are being built. There are tens of thousands of projects that are advancing the various aspects of the law of accelerating returns in diverse incremental ways. Regardless of near-term business cycles, the support for "high tech" in the business community, and in particular for software advancement, has grown enormously. When I started my optical character recognition (OCR) and speech synthesis company (Kurzweil Computer Products, Inc.) in 1974, high-tech venture deals totaled approximately $10 million. Even during today's high tech recession, the figure is 100 times greater. We would have to repeal capitalism and every visage of economic competition to stop this progression.

The economy (viewed either in total or per capita) has been growing exponentially throughout this century:

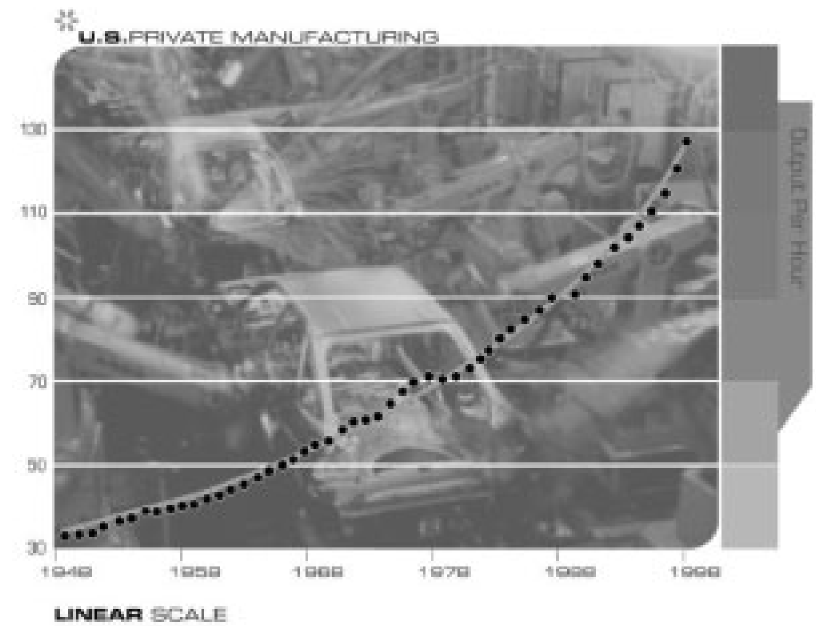


Note that the underlying exponential growth in the economy is a far more powerful force than periodic recessions. Even the "Great Depression" represents only a minor blip compared to the underlying pattern of growth. Most importantly, recessions, including the depression, represent only temporary deviations from the underlying curve. In each case, the economy ends up exactly where it would have been had the recession/depression never occurred.

Productivity (economic output per worker) has also been growing exponentially. Even these statistics are greatly understated because they do not fully reflect significant improvements in the quality and features of products and services. It is not the case that "a car is a car;" there have been significant improvements in safety, reliability, and features. Certainly, $1000 of computation today is immeasurably more powerful than $1000 of computation ten years ago (by a factor of more than 1000). There are a myriad of such examples. Pharmaceutical drugs are increasingly effective. Products ordered in five minutes on the web and delivered to your door are worth more than products that you have to fetch yourself. Clothes custom-manufactured for your unique body scan are worth more than clothes you happen to find left on a store rack. These sorts of improvements are true for most product categories, and none of them are reflected in the productivity statistics.

The statistical methods underlying the productivity measurements tend to factor out gains by essentially concluding that we still only get one dollar of products and services for a dollar despite the fact that we get much more for a dollar (e.g., compare a $1,000 computer today to one ten years ago). University of Chicago Professor Pete Klenow and University of Rochester Professor Mark Bils estimate that the value of existing goods has been increasing at 1.5 percent per year for the past 20 years because of qualitative improvements. This still does not account for the introduction of entirely new products and product categories (e.g., cell phones, pagers, pocket computers). The Bureau of Labor Statistics, which is responsible for the inflation statistics, uses a model that incorporates an estimate of quality growth at only 0.5 percent per year, reflecting a systematic underestimate of quality improvement and a resulting overestimate of inflation by at least 1 percent per year.

Despite these weaknesses in the productivity statistical methods, the gains in productivity are now reaching the steep part of the exponential curve. Labor productivity grew at 1.6 percent per year until 1994, then rose at 2.4 percent per year, and is now growing even more rapidly. In the quarter ending July 30, 2000, labor productivity grew at 5.3 percent. Manufacturing productivity grew at 4.4 percent annually from 1995 to 1999, durables manufacturing at 6.5 percent per year.



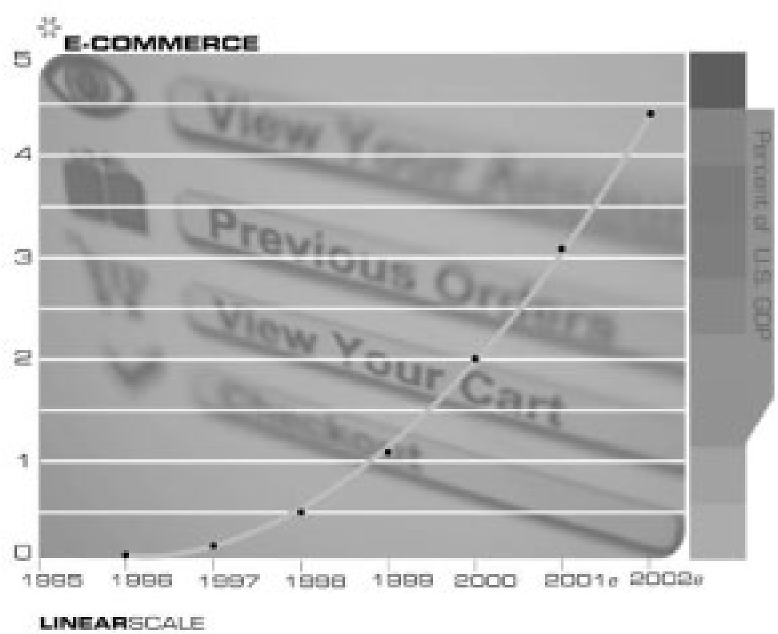
The 1990s have seen the most powerful deflationary forces in history. This is why we are not seeing inflation. Yes, it's true that low unemployment, high asset values, economic growth, and other such factors are inflationary, but these factors are offset by the double-exponential trends in the price-performance of all information-based technologies: computation, memory, communications, biotechnology, miniaturization, and even the overall rate of technical progress. These technologies deeply affect all industries. We are also undergoing massive disintermediation in the channels of distribution through the Web and other new communication technologies, as well as escalating efficiencies in operations and administration.

All of the technology trend charts above represent massive deflation. There are many examples of the impact of these escalating efficiencies. BP Amoco's cost for finding oil is now less than $1 per barrel, down from nearly $10 in 1991. Processing an Internet transaction costs a bank one penny, compared to over $1 using a teller ten years ago. A Roland Berger/Deutsche Bank study estimates a cost savings of $1200 per North American car over the next five years. A more optimistic Morgan Stanley study estimates that Internet-based procurement will save Ford, GM, and DaimlerChrysler about $2700 per vehicle.

It is important to point out that a key implication of nanotechnology is that it will bring the economics of software to hardware, i.e., to physical products. Software prices are deflating even more quickly than hardware.

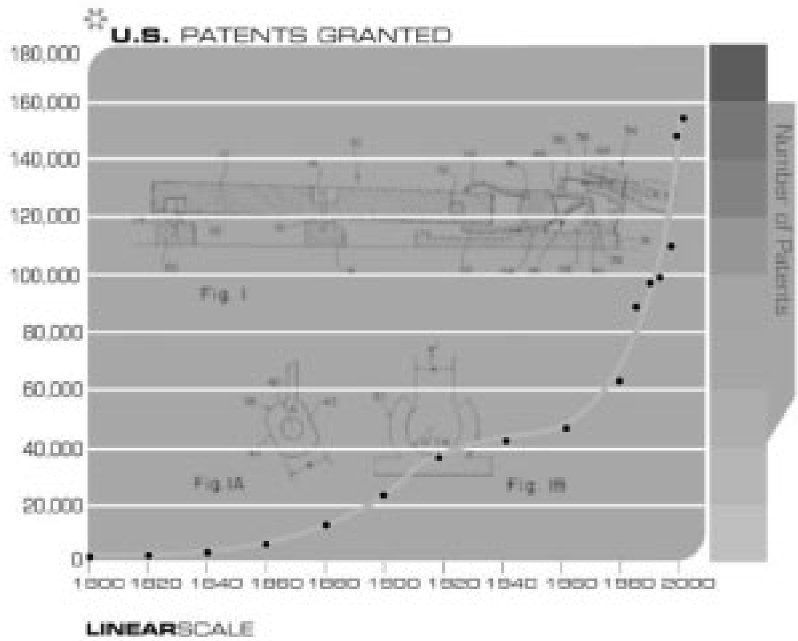
Software Price-Performance Has Also Improved at an Exponential Rate
(*Example: Automatic Speech Recognition Software*

	1985	1995	2000
Price	$5,000	$500	$50
Vocabulary Size (# words)	1,000	10,000	100,000
Continuous Speech?	No	No	Yes
User Training Required (Minutes)	180	60	5
Accuracy	Poor	Fair	Good



Current economic policy is based on outdated models that include energy prices, commodity prices, and capital investment in plant and equipment as key driving factors, but do not adequately model the size of technology, bandwidth, MIPs, megabytes, intellectual property, knowledge, and other increasingly vital (and increasingly increasing) constituents that are driving the economy.

Another indication of the law of accelerating returns in the exponential growth of human knowledge, including intellectual property. If we look at the development of intellectual property within the nanotechnology field, we see even more rapid growth.

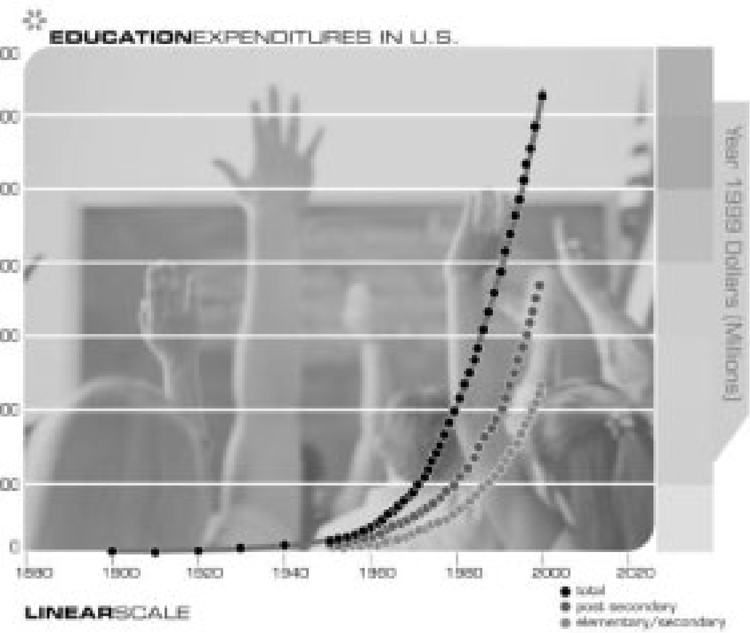


None of this means that cycles of recession will disappear immediately. Indeed there is a current economic slowdown and a technology-sector recession. The economy still has some of the underlying dynamics that historically have caused cycles of recession, specifically excessive commitments such as over-investment, excessive capital intensive projects and the overstocking of inventories. However, the rapid dissemination of information, sophisticated forms of online procurement, and increasingly transparent markets in all industries have diminished the impact of this cycle. So “recessions” are likely to have less direct impact on our standard of living. The underlying long-term growth rate will continue at a double exponential rate.

Moreover, innovation and the rate of paradigm shift are not noticeably affected by the minor deviations caused by economic cycles. All of the technologies exhibiting exponential growth shown in the above charts are continuing without losing a beat through this economic slowdown.

The overall growth of the economy reflects completely new forms and layers of wealth and value that did not previously exist, or least that did not previously constitute a significant portion of the economy (but do now): new forms of nanoparticle-based materials, genetic information, intellectual property, communication portals, web sites, bandwidth, software, data bases, and many other new technology-based categories.

Another implication of the law of accelerating returns is exponential growth in education and learning. Over the past 120 years, we have increased our investment in K–12 education (per student and in constant dollars) by a factor of ten. We have a one hundred fold increase in the number of college students. Automation started by amplifying the power of our muscles, and in recent times has been amplifying the power of our minds. Thus, for the past two centuries, automation has been eliminating jobs at the bottom of the skill ladder while creating new (and better paying) jobs at the top of the skill ladder. So the ladder has been moving up, and thus we have been exponentially increasing investments in education at all levels.


EDUCATIONEXPENDITURES IN U.S.
700,000
600,000
500,000
400,000
300,000
200,000
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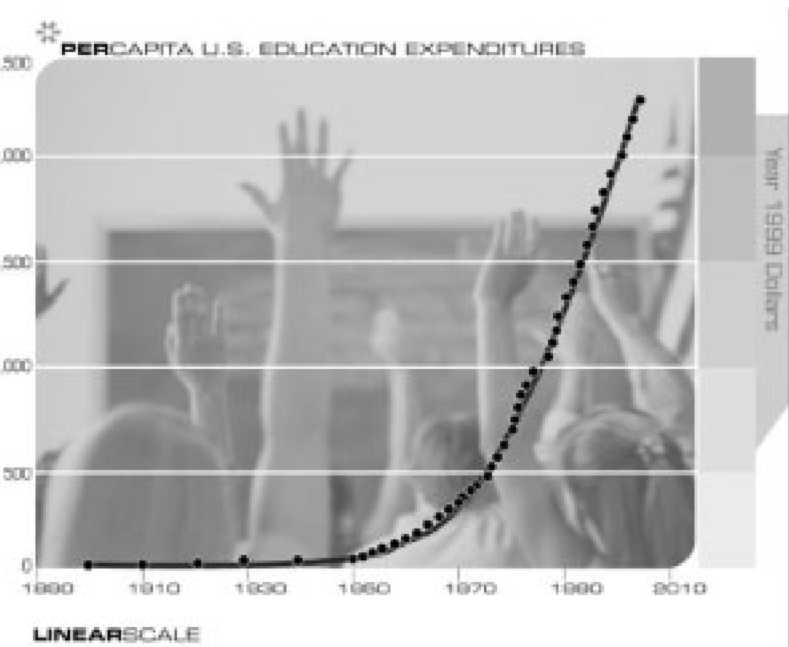
0
1880
1900
1920
1940
1960
1980
2000
2020
Year 1999 Dollars (Millions)
total
post secondary
elementary/secondary
LINEARSCALE


PERCAPITA U.S. EDUCATION EXPENDITURES
2,500
2,000
1,500
1,000
500
0
1890
1910
1930
1950
1970
1990
2010
Year 1999 Dollars
LINEARSCALE

The Deeply Intertwined Promise and Peril of Nanotechnology and Related Advanced Technologies

Technology has always been a double-edged sword, bringing us longer and healthier life spans, freedom from physical and mental drudgery, and many new creative possibilities on the one hand, while introducing new and salient dangers on the other. Technology empowers both our creative and destructive natures. Stalin's tanks and Hitler's trains used technology. We still live today with sufficient nuclear weapons (not all of which appear to be well accounted for) to end all mammalian life on the planet. Bioengineering is in the early stages of enormous strides in reversing disease and aging processes. However, the means and knowledge will soon exist in a routine college bioengineering lab (and already exists in more sophisticated labs) to create unfriendly pathogens more dangerous than nuclear weapons. As technology accelerates towards the full realization of biotechnology, nanotechnology and "strong" AI (artificial intelligence at human levels and beyond), we will see the same intertwined potentials: a feast of creativity resulting from human intelligence expanded many-fold combined with many grave new dangers.

Consider unrestrained nanobot replication. Nanobot technology requires billions or trillions of such intelligent devices to be useful. The most cost-effective way to scale up to such levels is through self-replication, essentially the same approach used in the biological world. And in the same way that biological self-replication gone awry (i.e., cancer) results in biological destruction, a defect in the mechanism curtailing nanobot self-replication would endanger all physical entities, biological or otherwise. I address below steps we can take to address this grave risk, but we cannot have complete assurance in any strategy that we devise today.

Other primary concerns include "who is controlling the nanobots?" and "who are the nanobots talking to?" Organizations (e.g., governments, extremist groups) or just a clever individual could put trillions of undetectable nanobots in the water or food supply of an individual or of an entire population. These "spy" nanobots could then monitor, influence, and even control our thoughts and actions. In addition to introducing physical spy nanobots, existing nanobots could be influenced through software viruses and other software "hacking" techniques. When there is software running in our brains, issues of privacy and security will take on a new urgency.

My own expectation is that the creative and constructive applications of this technology will dominate, as I believe they do today. However, I believe we need to invest more heavily in developing specific defensive technologies. As I address further below, we are at this stage today for biotechnology, and will reach the stage where we need to directly implement defensive technologies for nanotechnology during the late teen years of this century.

If we imagine describing the dangers that exist today to people who lived a couple of hundred years ago, they would think it mad to take such risks. On the other hand, how many people in the year 2000 would really want to go back to the short, brutish, disease-filled, poverty-stricken, disaster-prone lives that 99 percent of the human race struggled through a couple of centuries ago? We may romanticize the past, but up until fairly recently, most of humanity lived extremely fragile lives where one all-too-common misfortune could spell disaster. Substantial portions of our species still live in this precarious way, which is at least one reason to continue technological progress and the economic enhancement that accompanies it.

People often go through three stages in examining the impact of future technology: awe and wonderment at its potential to overcome age old problems; then a sense of dread at a new set of grave dangers that accompany these new technologies; followed, finally and hopefully, by the realization that the only viable and responsible path is to set a careful course that can realize the promise while managing the peril.

This congressional hearing was party inspired by Bill Joy's cover story for Wired magazine, *Why The Future Doesn't Need Us.* Bill Joy, co-founder of Sun Microsystems and principal developer of the Java programming language, has recently taken up a personal mission to warn us of the impending dangers from the emergence of self-replicating technologies in the fields of genetics, nanotechnology, and robotics, which he aggregates under the label "GNR." Although his warnings are not entirely new, they have attracted considerable attention because of Joy's credibility as one of our leading technologists. It is reminiscent of the attention that George Soros, the currency arbitrager and arch capitalist, received when he made vaguely critical comments about the excesses of unrestrained capitalism.

Joy's concerns include genetically altered designer pathogens, followed by self-replicating entities created through nanotechnology. And if we manage to survive these first two perils, we will encounter robots whose intelligence will rival and ultimately exceed our own. Such robots may make great assistants, but who's to say that we can count on them to remain reliably friendly to mere humans?

Although I am often cast as the technology optimist who counters Joy's pessimism, I do share his concerns regarding self-replicating technologies; indeed, I played a role in bringing these dangers to Bill's attention. In many of the dialogues and forums in which I have participated on this subject, I end up defending Joy's position with regard to the feasibility of these technologies and scenarios when they come under attack by commentators who I believe are being quite shortsighted in their skepticism. Even so, I do find fault with Joy's prescription: halting the advance of technology and the pursuit of knowledge in broad fields such as nanotechnology.

In his essay, Bill Joy eloquently described the plagues of centuries past and how new self-replicating technologies, such as mutant bioengineered pathogens and "nanobots" run amok, may bring back long-forgotten pestilence. Indeed these are real dangers. It is also the case, which Joy acknowledges, that it has been technological advances, such as antibiotics and improved sanitation, which have freed us from the prevalence of such plagues. Suffering in the world continues and demands our steadfast attention. Should we tell the millions of people afflicted with cancer and other devastating conditions that we are canceling the development of all bioengineered treatments because there is a risk that these same technologies may someday be used for malevolent purposes? Having asked the rhetorical question, I realize that there is a movement to do exactly that, but I think most people would agree that such broad-based relinquishment is not the answer.

The continued opportunity to alleviate human distress is one important motivation for continuing technological advancement. Also compelling are the already apparent economic gains I discussed above that will continue to hasten in the decades ahead. The continued acceleration of many intertwined technologies are roads paved with gold (I use the plural here because technology is clearly not a single path). In a competitive environment, it is an economic imperative to go down these roads. Relinquishing technological advancement would be economic suicide for individuals, companies, and nations.

The Relinquishment Issue

This brings us to the issue of relinquishment, which is Bill Joy's most controversial recommendation and personal commitment. I do feel that relinquishment at the right level is part of a responsible and constructive response to these genuine perils. The issue, however, is exactly this: at what level are we to relinquish technology?

Ted Kaczynski would have us renounce all of it. This, in my view, is neither desirable nor feasible, and the futility of such a position is only underscored by the senselessness of Kaczynski's deplorable tactics. There are other voices, less reckless than Kaczynski, who are nonetheless arguing for broad-based relinquishment of technology. Bill McKibben, the environmentalist who was one of the first to warn against global warming, takes the position that "environmentalists must now grapple squarely with the idea of a world that has enough wealth and enough technological capability, and should not pursue more." In my view, this position ignores the extensive suffering that remains in the human world, which we will be in a position to alleviate through continued technological progress.

Another level would be to forego certain fields—nanotechnology, for example—that might be regarded as too dangerous. But such sweeping strokes of relinquishment are equally untenable. As I pointed out above, nanotechnology is simply the inevitable end result of the persistent trend towards miniaturization that pervades all of technology. It is far from a single centralized effort, but is being pursued by a myriad of projects with many diverse goals.

One observer wrote:

> "A further reason why industrial society cannot be reformed. . .is that modern technology is a unified system in which all parts are dependent on one another. You can't get rid of the "bad" parts of technology and retain only the "good" parts. Take modern medicine, for example. Progress in medical science depends on progress in chemistry, physics, biology, computer science and other fields. Advanced medical treatments require expensive, high-tech equipment that can be made available only by a technologically progressive, economically rich society. Clearly you can't have much progress in medicine without the whole technological system and everything that goes with it."

The observer I am quoting is, again, Ted Kaczynski. Although one will properly resist Kaczynski as an authority, I believe he is correct on the deeply entangled nature of the benefits and risks. However, Kaczynski and I clearly part company on our overall assessment on the relative balance between the two. Bill Joy and I have dialogued on this issue both publicly and privately, and we both believe that technology will and should progress, and that we need to be actively concerned with the dark side. If Bill and I disagree, it's on the granularity of relinquishment that is both feasible and desirable.

Abandonment of broad areas of technology will only push them underground where development would continue unimpeded by ethics and regulation. In such a situation, it would be the less-stable, less-responsible practitioners (e.g., terrorists) who would have all the expertise.

I do think that relinquishment at the right level needs to be part of our ethical response to the dangers of 21st century technologies. One constructive example of this is the proposed ethical guideline by the Foresight Institute, founded by nanotechnology pioneer Eric Drexler, that nanotechnologists agree to relinquish the development of physical entities that can self-replicate in a natural environment. Another is a ban on self-replicating physical entities that contain their own codes for self-replication. In what nanotechnologist Ralph Merkle calls the "broadcast architecture," such entities would have to obtain such codes from a centralized secure server, which would guard against undesirable replication. I discuss these guidelines further below.

The broadcast architecture is impossible in the biological world, which represents at least one way in which nanotechnology can be made safer than biotechnology. In other ways, nanotech is potentially more dangerous because nanobots can be physically stronger than protein-based entities and more intelligent. It will eventually be possible to combine the two by having nanotechnology provide the codes within biological entities (replacing DNA), in which case biological entities can use the much safer broadcast architecture. I comment further on the strengths and weaknesses of the broadcast architecture below.

As responsible technologies, our ethics should include such "fine-grained" relinquishment, among other professional ethical guidelines. Other protections will need to include oversight by regulatory bodies, the development of technology-specific "immune" responses, as well as computer assisted surveillance by law enforcement organizations. Many people are not aware that our intelligence agencies already use advanced technologies such as automated word spotting to monitor a substantial flow of telephone conversations. As we go forward, balancing our cherished rights of privacy with our need to be protected from the malicious use of powerful 21st century technologies will be one of many profound challenges. This is one reason that such issues as an encryption "trap door" (in which law enforcement authorities would have access to otherwise secure information) and the FBI "Carnivore" email-snooping system have been controversial, although these controversies have abated since 9–11–2001.

As a test case, we can take a small measure of comfort from how we have dealt with one recent technological challenge. There exists today a new form of fully non-biological self replicating entity that didn't exist just a few decades ago: the computer virus. When this form of destructive intruder first appeared, strong concerns were voiced that as they became more sophisticated, software pathogens had the potential to destroy the computer network medium they live in. Yet the "immune system" that has evolved in response to this challenge has been largely effective. Although destructive self-replicating software entities do cause damage from time to time, the injury is but a small fraction of the benefit we receive from the computers and communication links that harbor them. No one would suggest we do away with computers, local area networks, and the Internet because of software viruses.

One might counter that computer viruses do not have the lethal potential of biological viruses or of destructive nanotechnology. This is not always the case; we rely on software to monitor patients in critical care units, to fly and land airplanes, to guide intelligent weapons in our current campaign in Iraq, and other "mission-critical" tasks. To the extent that this is true, however, this observation only strengthens my argument. The fact that computer viruses are not usually deadly to humans only means that more people are willing to create and release them. It also means that our response to the danger is that much less intense. Conversely, when it comes to self- replicating entities that are potentially lethal on a large scale, our response on all levels will be vastly more serious, as we have seen since 9–11.

I would describe our response to software pathogens as effective and successful. Although they remain (and always will remain) a concern, the danger remains at a nuisance level. Keep in mind that this success is in an industry in which there is no regulation, and no certification for practitioners. This largely unregulated industry is also enormously productive. One could argue that it has contributed more to our technological and economic progress than any other enterprise in human history. I discuss the issue of regulation further below.

Development of Defensive Technologies and the Impact of Regulation

Joy's treatise is effective because he paints a picture of future dangers as if they were released on today's unprepared world. The reality is that the sophistication and power of our defensive technologies and knowledge will grow along with the dangers. When we have "gray goo" (unrestrained nanobot replication), we will also have "blue goo" ("police" nanobots that combat the "bad" nanobots). The story of the 21st century has not yet been written, so we cannot say with assurance that we will successfully avoid all misuse. But the surest way to prevent the development of the defensive technologies would be to relinquish the pursuit of knowledge in broad areas. We have been able to largely control harmful software virus replication because the requisite knowledge is widely available to responsible practitioners. Attempts to restrict this knowledge would have created a far less stable situation. Responses to new challenges would have been far slower, and it is likely that the balance would have shifted towards the more destructive applications (e.g., software viruses).

The challenge most immediately in front of us is not self-replicating nanotechnology, but rather self-replicating biotechnology. The next two decades will be the golden age of biotechnology, whereas the comparable era for nanotechnology will follow in the 2020s and beyond. We are now in the early stages of a transforming technology based on the intersection of biology and information science. We are learning the "software" methods of life and disease processes. By reprogramming the information processes that lead to and encourage disease and aging, we will have the ability to overcome these afflictions. However, the same knowledge can also empower a terrorist to create a bioengineered pathogen.

As we compare the success we have had in controlling engineered software viruses to the coming challenge of controlling engineered biological viruses, we are struck with one salient difference. As I noted above, the software industry is almost completely unregulated. The same is obviously not the case for biotechnology. *A bioterrorist does not need to put his "innovations" through the FDA*. However, we do require the scientists developing the defensive technologies to follow the existing regulations, which slow down the innovation process at every step. Moreover, it is impossible, under existing regulations and ethical standards, to test defenses to bioterrorist agents. There is already extensive discussion to modify these regulations to allow for animal models and simulations to replace infeasible human trials. This will be necessary, but I believe we will need to go beyond these steps to accelerate the development of vitally needed defensive technologies.

For reasons I have articulated above, stopping these technologies is not feasible, and pursuit of such broad forms of relinquishment will only distract us from the vital task in front of us. In terms of public policy, the task at hand is to rapidly develop the defensive steps needed, which include ethical standards, legal standards, and defensive technologies. It is quite clearly a race. As I noted, in the software field, the defensive technologies have remained a step ahead of the offensive ones. With the extensive regulation in the medical field slowing down innovation at each stage, we cannot have the same confidence with regard to the abuse of biotechnology.

In the current environment, when one person dies in gene therapy trials, there are congressional investigations and all gene therapy research comes to a temporary halt. There is a legitimate need to make biomedical research as safe as possible, but our balancing of risks is completely off. The millions of people who desperately need the advances to be made available by gene therapy and other breakthrough biotechnology advances appear to carry little political weight against a handful of well-publicized casualties from the inevitable risks of progress.

This equation will become even more stark when we consider the emerging dangers of bioengineered pathogens. What is needed is a change in public attitude in terms of tolerance for needed risk.

Hastening defensive technologies is absolutely vital to our security. We need to streamline regulatory procedures to achieve this. However, we also need to greatly increase our investment explicitly in the defensive technologies. In the biotechnology field, this means the rapid development of antiviral medications. We will not have time to develop specific countermeasures for each new challenge that comes along. We are close to developing more generalized antiviral technologies, and these need to be accelerated.

I have addressed here the issue of biotechnology because that is the threshold and challenge that we now face. The comparable situation will exist for nanotechnology once replication of nano-engineered entities has been achieved. As that threshold comes closer, we will then need to invest specifically in the development of defensive technologies, including the creation of a nanotechnology-based immune system. Bill Joy and other observers have pointed out that such an immune system would itself be a danger because of the potential of "autoimmune" reactions (i.e., the immune system using its powers to attack the world it is supposed to be defending).

However, this observation is not a compelling reason to avoid the creation of an immune system. No one would argue that humans would be better off without an immune system because of the possibility of auto immune diseases. Although the immune system can itself be a danger, humans would not last more than a few weeks (barring extraordinary efforts at isolation) without one. The development of a technological immune system for nanotechnology will happen even without explicit efforts to create one. We have effectively done this with regard to software viruses. We created a software virus immune system not through a formal grand design project, but rather through our incremental responses to each new challenge. We can expect the same thing will happen as challenges from nanotechnology based dangers emerge. The point for public policy will be to specifically invest in these defensive technologies.

It is premature today to develop specific defensive nanotechnologies since we can only have a general idea of what we are trying to defend against. It would be similar to the engineering world creating defenses against software viruses before the first one had been created. However, there is already fruitful dialogue and discussion on anticipating this issue, and significantly expanded investment in these efforts is to be encouraged.

As I mentioned above, the Foresight Institute, for example, has devised a set of ethical standards and strategies for assuring the development of safe nanotechnology. These guidelines include:

- "Artificial replicators must not be capable of replication in a natural, uncontrolled environment."
- "Evolution within the context of a self-replicating manufacturing system is discouraged."
- "MNT (molecular nanotechnology) designs should specifically limit proliferation and provide traceability of any replicating systems."
- "Distribution of molecular manufacturing development capability should be restricted whenever possible, to responsible actors that have agreed to the guidelines. No such restriction need apply to end products of the development process."

Other strategies that the Foresight Institute has proposed include:

- Replication should require materials not found in the natural environment.
- Manufacturing (replication) should be separated from the functionality of end products. Manufacturing devices can create end products, but cannot replicate themselves, and end products should have no replication capabilities.
- Replication should require replication codes that are encrypted, and time limited. The broadcast architecture mentioned earlier is an example of this recommendation.

These guidelines and strategies are likely to be effective with regarding to preventing accidental release of dangerous self- replicating nanotechnology entities. The situation with regard to intentional design and release of such entities is more complex and more challenging. We can anticipate approaches that would have the potential to defeat each of these layers of protections by a sufficiently determined and destructive opponent.

Take, for example, the broadcast architecture. When properly designed, each entity is unable to replicate without first obtaining replication codes. These codes are not passed on from one replication generation to the next. However, a modification to such a design could bypass the destruction of the replication codes and thereby pass them on to the next generation. To overcome that possibility, it has been recommended that the memory for the replication codes be limited to only a subset of the full replication code so that there is insufficient memory to pass the codes along. However, this guideline could be defeated by expanding the size of the replication code memory to incorporate the entire code. Another protection that has been suggested is to encrypt the codes and to build in protections such as time expiration limitations in the decryption systems. However, we can see the ease with which protections against unauthorized replications of intellectual property such as music files has been defeated. Once replication codes and protective layers are stripped away, the information can be replicated without these restrictions.

My point is not that protection is impossible. Rather, we need to realize that any level of protection will only work to a certain level of sophistication. The "meta" lesson here is that we will need to continue to advance the defensive technologies, and keep them one or more steps ahead of the destructive technologies. We have seen analogies to this in many areas, including technologies for national defense, as well as our largely successful efforts to combat software viruses, that I alluded to above.

What we can do today with regard to the critical challenge of self-replication in nanotechnology is to continue the type of effective study that the Foresight Institute has initiated. With the human genome project, three to five percent of the budgets were devoted to the ethical, legal, and social implications (ELSI) of the technology. A similar commitment for nanotechnology would be appropriate and constructive.

Technology will remain a double-edged sword, and the story of the 21st century has not yet been written. It represents vast power to be used for all humankind's purposes. We have no choice but to work hard to apply these quickening technologies to advance our human values, despite what often appears to be a lack of consensus on what those values should be.

Biography for Raymond Kurzweil

Ray Kurzweil was the principal developer of the first omni-font optical character recognition, the first print-to-speech reading machine for the blind, the first CCD flat-bed scanner, the first text-to-speech synthesizer, the first music synthesizer capable of recreating the grand piano and other orchestral instruments, and the first commercially marketed large-vocabulary speech recognition. Ray has successfully founded and developed nine businesses in *OCR, music synthesis, speech recognition, reading technology, virtual reality, financial investment, medical simulation,* and *cybernetic art.* A11 of these technologies continue today as market leaders. Ray's web site, *KurzweilAI.net*, is a leading resource on artificial intelligence.

Ray Kurzweil was inducted in 2002 into the *National Inventors Hall of Fame,* established by the U.S. Patent Office. He received the $500,000 Lemelson-MIT Prize *(view the video)*, the Nation's largest award in invention and innovation. He also received the *1999 National Medal of Technology,* the Nation's highest honor in technology, from President Clinton in a White House ceremony. He has also received scores of other national and international awards, including the 1994 Dickson Prize (Carnegie Mellon University's top science prize), Engineer of the Year from Design News, Inventor of the Year from MIT, and the Grace Murray Hopper Award from the Association for Computing Machinery. He has received eleven honorary Doctorates and honors from three U.S. presidents.

He has received seven national and international film awards. His book, *The Age of Intelligent Machines,* was named Best Computer Science Book of 1990. His current best-selling book, *The Age of Spiritual Machines, When Computers Exceed Human Intelligence,* has been published in nine languages and achieved the #1 best selling book on *Amazon.com* in the categories of "Science" and "Artificial Intelligence."

Kurzweil Technologies

April 9, 2003

The Honorable Sherwood Boehlert
Chairman, Science Committee
2320 Rayburn Office Building
Washington, DC 20515

Dear Congressman Boehlert:

Thank you for the invitation to testify before the U.S. House of Representatives Committee on Science on April 9th for the hearing entitled, *The Societal Implications of Nanotechnology*.

In accordance with the Rules Governing Testimony, this letter serves as formal notice that I have received no federal funding directly supporting the subject matter on which I have testified, in the current fiscal year or either of the two proceeding fiscal years. I am a Director of Zyvex Corporation, a nanotechnology company that has received some federal funding. Also I have been an advisor and have a small amount of stock in Integrated Fuel Cell Technologies, Inc., which is not a nanotechnology company, but rather than an energy "MEMS" (Micro Electronic Mechanical Systems) company building hydrogen fuel cells on integrated circuits. I mention this because the application of MEMS (as a precursor to full nanotechnology) came up, along with specific reference to IFCT.

None of my own companies have received government funding for nanotechnology.

Sincerely,

Raymond Kurzweil
Chairman and CEO
Kurzweil, Technologies, Inc.

Chairman BOEHLERT. Thank you very much, Dr. Kurzweil. Dr. Colvin.

STATEMENT OF DR. VICKI L. COLVIN, EXECUTIVE DIRECTOR, CENTER FOR BIOLOGICAL AND ENVIRONMENTAL NANOTECHNOLOGY, ASSOCIATE PROFESSOR OF CHEMISTRY, RICE UNIVERSITY

Dr. COLVIN. Good morning, Chairman Boehlert, Ranking Member Hall, and Members of the House Science Committee. I will highlight the essential points of my written testimony with a modified structure. It is briefer in this oral statement.

The novel "Prey" describes a chilling scenario in which nanorobots begin preying on living creatures and reproducing. This is science fiction, not science fact. However, the public relations nightmare it could spawn is just as frightening to me, a nanotechnology researcher, as nanobots might be to some lay people. The good news is that it is not too late to ensure that nanotechnology develops responsibly and with strong public support.

New developments in technology, as you pointed out in your opening statement, usually start out with potential benefits to the economy, human health and quality of life being touted. In our center, we refer to that as the "wow index". At present, nanotechnology has a very high wow index. Whether it is smart clothing with computers woven into its fabric or drug delivery pumps you can turn on with a flashlight, nanotechnology is wowing everyone. However, every new technology brings with it a set of concerns that, if handled poorly, can turn "wow" into "yuck" and ultimately into bankrupt as the genetically modified foods industry discovered.

This fate is not inevitable. The founders of the Human Genome Project, instead of bearing potential controversies, have embraced them. They have committed at least three percent of their annual research budget to societal implications. I think it is because of the substantial debate this research has sparked that public opposition to this work has been minimal. These examples teach us that early and open exploration of the unintended impacts of new technology can derail the wow-to-yuck trajectory.

What are the societal and ethical issues for nanotechnology? No one has a crystal ball to predict the future. In spite of this, nanotechnology's yuck factor is rising due in part to the fiction of invisible nanorobots. Nanobots distract us from the less exciting but more real issues that are likely to rise in the area of environmental impact.

As a chemist, I know all too well how unforeseen consequences can destroy industries. From asbestos to DDT, society has paid a high price for not evaluating human health and ecosystem impacts before industries develop. The real losers are the businesses that enthusiastically embrace these new materials only to face expensive liability and clean-up claims later.

It may seem premature to consider these issues now for nanotechnology, however if you have used a sunscreen in the last year, your skin probably came into contact with nanoscale ceramics. Is this a cause for concern? No one knows. Nanoscale solids can interact with biological systems in unexpected ways. For example, you could wear a silver bracelet with no ill effects, however, if you actually eat nanoscale silver, which I wouldn't advise but some people do, you will turn yourself quite blue. Unintended exposure to nanoscale solids could have even more dire consequences, we just don't know very much about this problem. If we fail to answer these questions early, public acceptance of nanotechnology could be in jeopardy and the entire industry derailed.

It is critical to consider environmental impact as an essential component, especially for nanotechnology in the broad category of societal impact. At the center I direct, we consider the environmental consequences of engineered nanomaterials, but we can't do this alone. We need partners. Despite their rhetoric, there is little money and interest in societal impact research. Your help here is essential. You can use this legislation to strongly highlight the value that you, the policy makers, place on societal impact research. This value is not instinctively shared by researchers or their funding agencies. We justify our financial support to both you and the public by stressing the wow of what we do. Research that uncovers problems or postulates negative consequences is not widely pursued or rewarded.

Also, the NNI bill should recognize that societal impact research is very hard to do. It requires teams that predict the future and then decide what those futures might mean. The first step, technology forecasting, must be done by nanotechnologists that are closely involved with applications development. The second step requires both social and environmental scientists to evaluate the consequences. Only when both of these people—pieces come together can societal impact work have a meaningful impact on nanotechnology development. Such a large and complex collaborative effort is best managed, I believe, in a center environment.

In order to monitor the progress of societal impact research, especially in light of some of the barriers it faces, it would be essential to quantify its funding and its outputs. The advisory panel proposed in this legislation will be instrumental here in classifying which of the many NNI research efforts address truly societal impact. They can distinguish, for example, between projects aimed at developing new environmental applications from those aimed at evaluating environmental implications. Ultimately, how nanotechnology develops will depend on how its research monies are allocated. Do for nanotechnology what the Human Genome Project founders have done for sequencing genes. Invest five percent of the total research dollars in nanotechnology toward societal, ethical, and environmental impact studies. This is a small price to pay to ensure that nanotechnology develops responsibly and with strong public support.

Thank you for the opportunity to speak. I will be happy to answer questions.

[The prepared statement of Dr. Colvin follows:]

Prepared Statement of Vicki L. Colvin

Good morning Chairman Boehlert, Ranking Member Hall, and Members of the House Science Committee. Thank you for holding this important hearing to consider the societal and ethical impacts of nanotechnology.

Michael Crichton's novel *Prey* describes a chilling scenario in which swarms of nano-robots—equipped with memory, solar power generators, and powerful software—begin preying on living creatures and reproducing. This may be gripping science fiction; it is not science fact. It does, however, highlight a reaction that could bring the growing nanotechnology industry to its knees: fear. The perception that nanotechnology will cause environmental devastation or human disease could itself turn the dream of a trillion-dollar industry into a nightmare of public backlash. This negative response is possible even if the environmental and health threats never materialize. To nanotechnology researchers like myself, that prospect is all too real, and just as frightening as anything a sci-fi writer can imagine.

The good news is that its not too late to ensure that nanotechnology develops responsibly and with strong public support. The Center for Biological and Environmental Nanotechnology at Rice University is working toward that goal, and we believe that legislation such as the *Nanotechnology Research and Development Act of 2003* is central in avoiding this nightmare scenario.

The Wow Index

New developments in technology usually start out with strong public support, as the potential benefits to the economy, human health or quality of life are touted. At our center we call this the "wow index." Genetic engineering promised a revolution in medical care, including the ability to cure or prevent diseases with a genetic basis such as Huntington's disease, hemophilia, cystic fibrosis and some breast cancers. Manipulation of the genome also promised a revolution in how food is produced, by engineering crops with increased yields and longer shelf-lives.

At present, nanotechnology has a very high wow index. For the past decade, nanotechnologists have basked in the glow of positive public opinion. We've wowed the public with our ability to manipulate matter at the atomic level and with grand visions of how we might use this ability. All this "good news" has created a growing perception among business and government leaders that nanotechnology is a powerful platform for 21st century technologies. The good news has given nanotechnology a strong start with extraordinary levels of focused government funding, which is starting to reap tangible benefits to society.

The Yuck Index

However, every new technology brings with it a set of societal and ethical concerns that can rapidly turn "wow" into "yuck." The genetic manipulation of crops grown for human consumption spawned a host of ethical concerns about the advisability of tinkering with the natural order. The public backlash against genetically modified organisms (GMOs), which detractors labeled "Frankenfoods," crippled the industry and ultimately cost billions in lost future revenues.

The campaign against GMOs was successful despite the lack of sound scientific data demonstrating a threat to society. In fact, I argue that the lack of sufficient public scientific data on GMOs, whether positive or negative, was a controlling factor in the industry's fall from favor. The failure of the industry to produce and share information with public stakeholders left it ill-equipped to respond to GMO detractors. This industry went, in essence, from "wow" to "yuck" to "bankrupt." There is a powerful lesson here for nanotechnology.

In contrast, the Human Genome Project provides a good model for how an emerging technology can defuse potential controversy by addressing it in the public sphere. Mapping of the human genome carries with it many of the same potential concerns as do other fields of genetic research. The increased availability of genetic information raises the potential for loss of privacy, misuse by the police and insurance companies, and discrimination by employers. The founders of the Human Genome Project did not try to bury these legitimate concerns by limiting public discourse to the benefits of this new knowledge. Instead, they wisely welcomed and actively encouraged the debate from the outset by setting aside five percent of the annual budget for a program to define and address the ethical, legal and other societal implications of the project.

I sincerely hope that we can learn from this example: early and open discussions of the societal and ethical impacts of new technologies improve their staying power, save taxpayers money, and benefit our society. In effect, early research into unintended consequences redirects the wow-to-yuck trajectory.

Societal, Ethical and Environmental Issues in Nanotechnology

I'd now like to turn to the question of what 'societal and ethical' issues mean within the specific context of nanotechnology. No one has a crystal ball to predict exactly how nanotechnology will change our lives. Unfortunately, due to in part to unrealistic scenarios like the one in *Prey,* nanotechnology's yuck index is rising as people take as fact the fiction of 'invisible nanorobots;' this issue is a distraction from the real and perhaps more mundane issues that this new technology area is facing, particularly in the area of environmental impact.

Nanotechnologies in their diverse forms all share one feature: their reliance on nanoscale materials. In short, nanotechnologies require 'stuff.' This stuff may be a familiar material such as silicon or gold that exhibits unique and very valuable properties when it is "nanosized." Like any material, whether polymers or silicon chips, nanomaterials require energy to manufacture and generate waste to dispose of. It will prove to be expensive to ignore these issues until a mature industry is developed; for example, a growing fraction of the cost of a Pentium chip is not in the raw materials but in the energy and waste disposal costs. Ultimately the industry and society will benefit if we plan now to create a nanomanufacturing industry that minimizes waste production and energy use.

Nanomaterials themselves may also have unintended environmental consequences. As a chemist I know all too well how unforeseen health effects can destroy industries based on complex materials. From asbestos to DDT we have, as a society, paid an enormous price for not evaluating toxicological and ecosystem impacts before industries develop. The real losers here are not environmentalists; instead they are the businesses who enthusiastically embrace new materials, only to face a decade later debilitating liability claims from employees, consumers and governments. And in the case of nanotechnology, the ultimate losers may be the American taxpayers who invested over one billion dollars in nanomaterials research without any hard data on their toxicological and environmental effects.

This might seem like a distant issue with no effects on you or your constituents. However, if you have used a sunscreen in the last year it is possible that your skin came in contact with nanoscale ceramics. Is this a cause for concern? No one knows. It is remarkable that I must answer this way for a field with the funding levels and cachet of nanotechnology. Still, there are some general principles which help us think through the issue. Nanomaterials are valuable in many technologies because they interact quite differently with the body than larger materials. For example, you can wear a silver bracelet with no ill effects but if you eat too much nanoscale silver, as some people have in the belief it has various health benefits, you will turn yourself blue. Finely divided solids have access to areas of the body and interact with biological systems in completely unexpected ways, which is exactly why they are so powerful in medical applications. The converse of this is that unintended exposures—of research workers, factory workers, and the general public—to nanoscale solids could have more dire consequences than turning skin blue. Or they could turn out to be benign. We just don't know. If we fail to answer these questions early, public acceptance of nanotechnologies could be in jeopardy, and the entire industry derailed.

Avoiding the Wow-to-Yuck Trajectory for Nanotechnology

As one of six Nanoscale Science and Engineering Centers funded by the National Science Foundation, CBEN has a mandate to clear major roadblocks to nanotechnology commercialization. We have identified public acceptance as one of these possible roadblocks, and believe that we must look beyond the good news about nanotechnology and precisely characterize the unintended consequences of nanotechnology. We seek to avoid the path traveled by the GMO industry by encouraging the industry to answer the tough questions about societal and environmental impacts while it is still developing.

We need partners in this endeavor. Based on the recent National Research Council report and our own experience, there is little money and interest in the societal, ethical and environmental impact of nanotechnology, despite the rhetoric. Your help here is essential.

The central problem is simply one of human nature: people will instinctively focus on the positive 'wow' potential of nanotechnology. It is a belief in these positive outcomes that motivates researchers, students and most importantly funding agencies. It is not surprising that there has been little interest from nanotechnologists in studying negative implications. At EPA last year, for example, their call for proposals on nanotechnology applications received over a hundred responses while the nanotechnology environmental impact requests, which had much smaller project awards, received only a handful. There is also little incentive for funding agencies to expend their precious resources on this area. For example, when asked to appear before committees like this to justify their existence, I would doubt that federal agencies choose to highlight their research into the possible downsides of the technologies they develop.

There are concrete steps you can take to counteract this inevitable bias. Through legislation such as this, the National Nanotechnology Initiative can make impact studies a priority and, most critically, articulate the arguments for this focus. Policy-makers such as yourselves can look past the 'Wow' messages from funding agencies and continually emphasize the need for technical progress to be placed in a social context. Additionally, we must turn to our educational process as well. At CBEN we have found the 'wow-to-yuck' message very successful at conveying to students and researchers alike how ignorance of the long-term costs of nanotechnology could cripple the field.

Societal, ethical and environmental impact studies are also hard because they must envision a future technological reality. How can the social scientists and environmental engineers best equipped to complete this research choose which possible futuristic nanotechnology or nanomaterial to study? They could look to concrete data, such as the grand challenges of the NNI, to evaluate what specific technological goals have been articulated. Even better, they could partner with subject-matter experts early on. In this way they could study in real-time an evolving technology, and provide feedback to the researchers and students responsible for its development. For societal impact studies to be credible and effective, we must demand the active participation of nanotechnologists in the work. This would be best achieved by affiliating social scientists with major national nanotechnology centers, so as to provide investigators with a broad array of people and research to choose from.

While words can go a long ways, ultimately how nanotechnology develops will be critically sensitive to how its research monies are allocated. I agree with the National Research Council report that suggested that societal, environmental and ethical studies of nanotechnology are underfunded. For example, EPA's investment in nanotechnology, five million dollars per year, has been focused on nanotechnologies for environmental applications; only last year was $500,000 set aside for environmental impact work. NSF also funds basic research in nanoscale environmental issues, but CBEN's limited efforts are the only example I am aware of that consider specifically the environmental impact of engineered nanoparticles. If I had to guess, I would estimate that of the nearly one billion dollars slated to go to nanotechnology this year not even one percent is directed specifically towards studying the societal, ethical and environmental impact of nanotechnology. A tangible symbol of your commitment to this kind of research would be to set a target research funding for the area; the three to five percent rule used by the Department of Energy in the Human Genome Project would be a good starting point.

As a young nanotechnologist, in twenty or thirty years I want to see nanotechnology changing people's lives, all for the better. I believe that this can only come to pass by honest, early and sincere exploration of all the risks and benefits of this transformative new area. We have a unique opportunity to guide a nascent industry in the right direction from the outset. The time is now.

Thank you for bringing this issue into the spotlight. I welcome questions regarding my testimony.

BIOGRAPHY FOR VICKI L. COLVIN

Dr. Vicki Colvin has been on the faculty at Rice since the fall of 1996. As a physical chemist interested in complex materials problems, her group includes a diverse range of synthetic chemists, physical chemists and applied physicists. Specific research areas include template chemistry, meso- and macroporous solids, nanocrystalline oxides, photonic band gap materials and confined glasses.

Prior to her start at Rice, she was a member of the technical staff at Bell Labs where she developed new materials for holographic data storage. She received her Ph.D. in 1994 at U.C.–Berkeley under the direction of Dr. Paul Alivisatos. Her undergraduate degree, a B.S. in chemistry and physics, was completed in 1988 at Stanford University.

This year she has been named an Alfred P. Sloan research fellow and a Beckman Young Investigator. Previous awards include a Research Innovation Award (Research Corporation), Phi Beta Kappa Teaching Prize, NSF–YI award, a Dreyfus New Faculty Award and the ACS Victor K. LaMer Prize. She is the author of over 25 refereed publications, 3 patents and one book chapter.

RICE

DEPARTMENT OF CHEMISTRY
WIESS SCHOOL OF NATURAL SCIENCES

July 31, 2003

The Honorable Sherwood Boehlert
Chairman, Science Committee
2320 Rayburn Office Building
Washington, DC 20515

Dear Congressman Boehlert:

Thank you for the invitation to testify before the U.S. House of Representatives Science Committee on April 9 for the hearing entitled *The Societal Implications of Nanotechnology*. In accordance with the Rules Governing Testimony, this letter serves as formal notice of the Federal funding I currently receive in support of my research.

$10,540,000, Grant No. EEC-0118007, National Science Foundation, "NSEC: Center for Biological and Environmental Nanotechnology", 2002-2007.

$149,978, Grant No. ECS-9986534, National Science Foundation, "Using Protein Crystals as Templates", 2000-2003.

$1,200,000 Grant No. CHE-0103174, National Science Foundation, "NIRT: Protein Crystals: New Template", 2001-2004

$8,000 Grant No.DMR-0239969, National Science Foundation, "From Nanomaterials to Nanotechnology", 2002-2004.

$450,000 Grant No. 03012303, National Science Foundation, "MRI: Acquisition of a Scanning XPS", 2004-2007.

$24,695 Grant No. 03072501, National Science Foundation, "NSF-EC Workshop: From Nanomaterials", 2002-2004.

Sincerely,

Vicki L. Colvin

RICE UNIVERSITY · DEPARTMENT OF CHEMISTRY–MS 60 · P.O. BOX 1892 · HOUSTON, TEXAS 77251-1892
6100 MAIN STREET · HOUSTON, TEXAS 77005 · PHONE: 713-348-4082 · FAX: 713-348-5155 · E-MAIL: chem@rice.edu

Chairman BOEHLERT. Thank you very much, Dr. Colvin. I would appreciate, on behalf of the Committee, when you return to Rice, that great institution, if you extend our best wishes to Dr. Neil Lane——

Dr. COLVIN. I sure will.

Chairman BOEHLERT [continuing]. The immediate past director of the National Science Foundation and a very distinguished American. And now from the great Empire State, home of the Syracuse Orangemen, national basketball champions, I bring you—well, I have to do it, you know. I bring you Dr. Langdon Winner. Dr. Winner.

STATEMENT OF DR. LANGDON WINNER, PROFESSOR OF POLITICAL SCIENCE, DEPARTMENT OF SCIENCE AND TECHNOLOGY STUDIES, RENSSELAER POLYTECHNIC INSTITUTE

Dr. WINNER. Mr. Chairman, distinguished Members, I want to thank you for inviting me to testify this morning. Is this working? There we go. Thanks.

It is clear that nanotechnology is an emerging field of research with an enormous power to alter our way of life in decades to come. If one looks at previous episodes of technological transformation, it becomes clear how crucial it is to ask who gets to define what the transformation will involve. Typically what happens is the promoters of the new technology, those with the most to gain in the short run, are the ones who speak first and most loudly. The boosters predict a wide range of practical benefits, new products, services, efficiencies, improvements of all kinds. Later, as people in society at large take notice, they ponder predictions of a world transformed and begin to raise questions about the benefits and drawbacks, the range of social, economic, political, and environmental outcomes involved. And eventually, this constituency may ask for a voice in making decisions about where, how, and to what extent the emerging technology will be applied.

Now enthusiasts like to think that their technologies will enter the world rather smoothly. Emerson's famous dictum, "Build a better mousetrap and the world will beat a path to your door," is one that many technologists still prefer. What actually happens, however, is far more messy and complicated. The acceptance of any technology requires the building of a broad, social coalition that agrees to support its introduction and use. So the test of whether or not a technology is acceptable is ultimately whether enough people agree that "yes, these new methods make sense."

Alas, too often those who try to shepherd new technologies into being adopt strategies that cripple processes through which consensus, coalition, and balanced choices might arise. This strategy can backfire, producing unhappy surprises at the end of the development process. Instead of building a broad national and international base that supports one's innovation, one finds distrust and resistance.

An example of technological backfire is evident in the crisis that now surrounds biotechnology. Here, the social coalitions of support, neglected or even scorned as biotech development moved forward, have now evaporated in key areas of application. For reasons they find entirely sensible, for example, nations in the European Union now refuse to buy genetically modified foods from the United States. What this suggests is the failure to provide open, thorough, honest attention to the broader social, political, and cultural contexts that influence acceptance or rejection of emerging technologies can lead to disaster. Late in the process, it does little good to tell those who are unwilling that they are simply being irrational. To paraphrase yet again, Mr. Chairman, the great American philosopher, Yogi Berra: If people don't want to adopt your better mousetrap, nobody is going to stop them.

I will move quickly over the kinds of concerns that are often raised these days about nanotechnology. I will have to admit that I know too little to judge the likelihood of the various scenarios, both the optimistic and pessimistic ones. And indeed, I doubt that anyone at present has the required knowledge to judge these matters. That makes it all the more urgent to face the final question that the Committee posed to me in the Chairman's letter: How can research on the societal and ethical concerns be integrated into the research and development process? Clearly, there is a need to initiate systematic studies of the social and ethical dimensions of nanotechnology. We need broad-ranging, detailed, intellectually rigorous inquiries conducted by persons who have no financial or institutional stake that might skew the questions asked or the answers proposed.

Studies of this kind could be launched in a number of ways including funding truly cross-disciplinary programs in universities and research centers, asking them to scope out the issues and policy alternatives. But I would not advise you simply to pass the Nanoethicist Full Employment Act, sponsoring the creation of a new profession. For it seems to me that something more is needed. Over many decades, there has been the tendency in government-funded research to exclude the participation of those who are the ultimate stakeholders, the general public. Citizens pay the bills for the work unfolding. They, their children, and grandchildren will be the ones to experience the ultimate outcomes, good or bad. Why not include the public in deliberations about nanotechnology early on in the process rather than after the products reach the market?

In that light, I believe Congress should seek to create ways in which small panels of ordinary, disinterested citizens, selected in much the same way that we now choose juries in cases of law, be assembled to examine important societal issues about nanotechnology. These panels should study relevant documents, hear expert testimony from those doing the research, listen to arguments about technical applications and consequences from a variety of standpoints, deliberate on what they have been hearing, write reports offering policy advice.

There is now, in fact, in the National Science Foundation, a research program that funds experimental citizens panels of the sort I have described. I would suggest that Congress build upon these very fruitful experiments and specify, perhaps in the current legislation, citizens panels as one additional way to inform public debate about the societal and ethical dimensions of nanotechnology.

Mr. Chairman, these days we often hear how important it is to be innovative in emerging technical fields. Here is a way that Congress could be truly innovative, creating new ways for citizen stakeholders to join in the study and evaluation of new technologies.

Thank you for considering these ideas and suggestions.

[The prepared statement of Dr. Winner follows:]

PREPARED STATEMENT OF LANGDON WINNER

I want to thank the Committee on Science for inviting me to testify this morning. I will do my best to respond directly to the specific issues you have asked me to consider.

> *"What factors influence the successful adoption of new technologies into society? What questions should be asked during the research and development phase to help minimize the potentially disruptive impact of transformational technology developments?"*

Nanotechnology is an emerging technology with enormous potential to alter our way of life in decades ahead. It is by no means the first emerging technology to generate sweeping changes in society and the environment, nor will it be the last.

If one looks at previous episodes of technological transformation, it becomes clear how crucial it is to ask: Who gets to define what the transformation will involve? Typically, what happens is that the promoters of a new technology, those with the most to gain in the short run, are the ones who speak first and most loudly. The boosters predict a wide range of practical benefits—new products, services, efficiencies, improvements of all kinds. Indeed, they usually proclaim that there is a revolution just around the corner, one that will alter society for the better, making us wealthier, wiser, more democratic, and stronger in community bonds.

Often the promoters try a clever ploy, announcing that the changes on the horizon are "inevitable," beyond anyone's power to guide or significantly alter. In advertisements, World's Fairs exhibitions, and public relations campaigns, proclamations of inevitability have long been standard themes.

In contrast, those who have concerns about how the technology may develop and what its ultimate outcomes will be tend to speak later and more hesitantly. As people in society at large take notice, they ponder predictions of a world transformed and begin to raise questions about the benefits and drawbacks, the range of social, economic, political, and environmental consequences involved. Eventually, this broader constituency may ask for a voice in making decisions about where, how and to what extent the emerging technology will be applied.

It is fairly common for those who voice concerns about the social, economic, and environmental consequences of technological change to be denounced as irrational, unscientific and even anti-technology. Thus, Rachel Carson's modest report in *The Silent Spring* about the environmental destruction caused by the use of chemical pesticides brought heated denials from the chemical industry and attacks on Ms. Carson's scientific credentials (even though she was a noted scientist) and flagrant efforts to destroy her reputation. Of course, we now think of Rachel Carson as a hero, one able to focus our society's awareness of environmental problems and solutions. But as she raised her voice, calling our attention to the consequences of spreading poisons through the environment, she was derided as ill-informed, an enemy of progress.

Recurring episodes of this kind show why it is important to open the study and discussion about emerging technologies to the light of day, and to do this sooner, rather than later, in the process of planning, development and application.

The claim that a particular development is "inevitable" is particularly unhelpful in this regard. It suggests that people who have recently become aware of potentially significant changes to their way of life have no legitimate role in the negotiations. After all, who would be so foolish as to make suggestions when faced with the "inevitable"? As the motto of the 1933 World's Fair in Chicago informed visitors, "Science Finds—Industry Applies—Man Conforms."

But, in fact, technological change is never foreordained, the future never foreclosed. Real choices need to be identified, studied, and acted upon despite recurring efforts to say, "Sorry, you're too late. Your participation won't be needed, thanks."

Indeed, it seems increasingly clear that open deliberations about technological choices are crucial to the eventual acceptance or rejection of emerging technologies. The boosters like to think that their technologies will enter the world rather smoothly. Emerson's famous dictum, "Build a better mousetrap and the world will beat a path to your door," is an idea many technologists still prefer. What actually happens, however, is far more messy and complicated. The acceptance of any technology requires the building of a broad social coalition that agrees to support its introduction and use. Often there are alternative devices and systems, new ones and older ones, jockeying for this support. The test of whether or not a technology is acceptable is ultimately whether enough people agree that "yes, the new methods make sense."

Alas, all too often those who try to shepherd new technologies into being adopt strategies that cripple the processes through which consensus, coalition, and balanced choices might arise. This strategy can backfire, producing unhappy surprises at the end of the development process. Instead of building a broad national and international base that supports one's innovation, one finds distrust and stiff resistance.

This was certainly the case in the development of nuclear power in the United States. For many years plans were made by talented but inward-looking elites in government, business and the military who thought they knew best what the public would want. They regaled the populace with lovely propaganda about "the friendly atom" and "electricity too cheap to meter," but avoided going public about serious problems that the insiders knew about—the real costs of the plant, safety issues involved in their design, and the problem of nuclear waste disposal.

When these deeper problems finally did surface powerfully in the 1970s and 1980s, the social coalition that proponents of nuclear power hoped would support them suddenly collapsed. The building of nuclear power plants in the U.S. was halted, possibly forever.

Another episode of technological backfire, one perhaps more relevant to the rise of nanotechnology, is evident in the crisis that now surrounds biotechnology. Once again, the social coalition of support, neglected or even scorned as biotech development moved ahead, has now evaporated in key areas of application. For reasons they find entirely sensible, nations in the European Union now refuse to buy genetically modified foods from the U.S. In a similar way, faced with severe famine, Zambia has refused to accept GMO corn, even as a charitable gift.

What this suggests is that the failure to provide open, thorough and honest attention to the broader social, political and cultural contexts that influence the acceptance or rejection of emerging technologies can lead to disaster. Late in the process, it does little good to tell those who are unwilling that they're being irrational or that there is something woefully defective in their culture (not ours). To paraphrase the great American philosopher, Yogi Berra: If people don't want to adopt your better mousetrap, nobody's going to stop them.

I hope that the legislation you are considering, especially its provisions that support research on social and ethical implications of nanotechnology, will help create new practices and institutions in which all the important questions will be rigorously explored. I cannot predict whether or not broadly based, effective social coalitions will form around nanotech projects. I do know that it is increasingly risky to ignore or exclude the great multiplicity of groups and interests that would like to have a voice in defining what these technologies are and what they mean. In fact, wise policy would try to stimulate understanding of the implications of the technology on a broad scale, fostering widespread study and discussion open to everyone.

The Committee has asked, "What are the current concerns about existing and potential applications of nanotechnology science and engineering?"

Nearly two decades after the publication of Eric Drexler's *Engines of Creation,* a number of concerns about nanotechnology are finally attracting wide attention.

Some observers predict that particular materials produced by molecular nanotechnology (MNT) will turn out to be environmentally destructive.

Some worry that products of MNT could, in some configuration of events, prove hazardous to human health.

A recurring nightmare is that promised inventions in self-replicating systems might escape the boundaries originally established for them and begin to wreak havoc. As novelist Michael Crichton recently commented, "Imagine a mass of tiny computers, each smaller than a speck of dust, programmed to fly in a cloud over a country like Iraq and send back pictures. Imagine the computers begin to evolve and the aggregate cloud becomes a death dealing swarm that threatens mankind—a mechanical plague."

Others hear about ambitious proposals to employ nanotechnology and other "convergent" technologies to create (decades from now) a race of posthumans. Those not yet persuaded that this is "inevitable" wonder whether it's a good idea to seek to divide the human species in this manner and whether public funds should be spent on such ghoulish research.

Another persistent concern is that the rise of this field will not, as promised, be of general social benefit, but will simply amplify trends long under way—the concentration of wealth and power in the hands of the few and a widening gap between haves and have-nots in the U.S. and around the globe. Historically speaking, predictions the latest and greatest technology will equalize wealth and opportunity have usually proven false, a fact that never deters boosters of the "next big thing" from promising that this time (!) the economic and social developments will be universally shared.

Faced with the various possibilities described in writings about this new field of research, I must admit that I know too little to judge the likelihood of various scenarios, both optimistic and pessimistic. Indeed, I doubt that anyone has this knowledge at present. Rather than play Cassandra (or Norman Vincent Peale), I would simply note three overriding questions that ought to be considered as our society decides which proposals for nanotechnology research are worth sponsoring.

(1) Should we continue long-standing efforts to conquer and dominate nature rather than seek harmony with natural structures and processes?

During the past two centuries, the desire to conquer nature has often seemed synonymous with progress. Dam the rivers, drain the swamps, harvest the forests, and bring all plants and animals under human control—such counsel seemed eminently sensible. More recently, however, as some unhappy consequences of this ham-fisted approach have surfaced, many scientists, engineers, designers, and entrepreneurs have affirmed that seeking harmony with nature is a more promising technological and economic approach.

Unfortunately, this recognition seems to have escaped the enthusiasts of nanotechnology for whom the prospect of conquering nature right down to the last molecule and atom seems positively invigorating. It appears that God's creation is, alas, not all that it should be. Fortunately, it can now be refashioned by a new generation of godlike spirits who live in Cambridge, Palo Alto, the Research Triangle, and other concentrations of high tech brilliance. Thus, the peculiar values of the American middle class, so exquisitely realized in Happy Meals, SUVs, $200 Nike sneakers, and botox wrinkle treatments, will now be read into the smallest crevasses of the material universe. This is something to look forward to.

All of it occurs at a time in which it should be clear that strategies for dominating nature through brute force have failed repeatedly. For example, the creation of larger, technically more sophisticated fishing boats with better and better ways to track and catch fish has brought astonishing returns. Although it was a difficult battle and took many years to complete, we have finally conquered the Atlantic cod. The poor creature has not raised the white flag. It is simply disappearing from the nets and from the nation's supply of healthy protein.

I understand the obsession with dominating nature and the desire for power and wealth it reflects. These tendencies are a dreary, but recurring presence in modern life. Nevertheless, it is still worth inquiring: Why should American taxpayers be asked to subsidize ever more systematic assaults on natural realm? If they knew the kinds of projects sometimes proposed in this domain, how would they feel about them?

At present we see a wide range of scientific and technological strategies that try to work closely with nature rather than impose imperial dominance. It is interesting that these programs—ones that stress "natural capitalism," "green design" "biomimicry," and "sustainable economy"—point to a new industrial revolution, but one quite different from the revolution described by proponents of nanotechnology. Is it possible that the rush to nanotech will come into conflict effort to create a socially harmonious, ecological sustainable future? That prospect seems entirely likely.

(2) Should we actively promote a path development in which technical means become the driving force that shapes social ends?

The unfolding of nanotechnology may become yet another instance of a familiar phenomenon in which powerful techniques emerge from the lab and then go looking for uses. This pattern defies common sense understandings of the proper relationship between human ends and technical means.

In the common sense sequence, one begins by asking: What are our needs? What fundamental purposes define our inquiries? After the basic social ends have been clarified, compared, debated, and evaluated, we then move on to make choices among existing means, including newly developed technical devices.

As one reads reports coming from scientists and policy makers interested in nanotechnology and converging technologies in several areas of scientific and technological development, one does not see the common sense ends/means thinking at work. In writings on nanotechnology, there seems little willingness to ask: What are society's basic needs at present? What basic goals define our sense of well-being going forward?

What we find instead is a kind of opportunistic means-to-ends logic. Researchers and institutions interested in doing molecular and atomic scale engineering scan the horizon to see what opportunities might be identified as justifications for public funding and private investment.

Thus, enterprising nanotechnologists notice applications that might deliver medical doses tailored to specific cells.

Looking at the sheer size of the Department of Defense budget, nanotech promoters begin imagining ways in which the technology might provide new weapons and other devices to the military. Yes, there's always a lot of money in that.

Others catch on to this lucrative game and say, well, perhaps research on a range of nanotech applications could help the elderly or people with disabilities.

In sum, what we see here are tools that evolve quickly in response to a variety of internal research priorities and then go opportunistically looking for things to do. And, of course, one can always find something.

I am pleased that Congress is prepared to offer support for study of the societal and ethical dimensions of an important new field of scientific and technical research. But I fear that the manner in which the work is done will reproduce the kind of backwards logic that has shaped far too much of American technological development in recent decades. It is a logic that justifies the creation of a wide range of flashy new gadgets but cannot be bothered to examine the most urgent facts about the human condition in our time.

(3) Is it wise to experiment with technological applications likely to produce irreversible effects?

As a general matter, technologies should be judged superior if the consequences of their use are reversible. Some common projections about the outcomes of nanotechnology point to effects that could never be recalled from the environment or from the species with which nano-systems interact. As we scope out the possibilities here, we need to ask: Would particular paths of research and development risk opening Pandora's box? If so, how can present policies help eliminate that menace?

The final question the Committee has asked me to address is probably the one most important for the specifics of the legislation. "How can research on the societal and ethical concerns relating to nanotechnology be integrated into the research and development process?"

A growing number of scientists, scholars, university administrators, and social activists express a vital interest in this topic. Clearly, there is need to initiate systematic studies of the social and ethical dimensions of nanotechnology. We need broad-ranging, detailed, intellectually rigorous inquiries conducted by persons who have no financial or institutional stake that might skew the questions raised or constrain the answers proposed.

Studies of this kind could be launched in a number of ways, including funding truly cross-disciplinary programs in universities to scope out key issues and policy alternatives. But I would not advise you to pass a Nanoethicist Full Employment Act, sponsoring the creation of a new profession. Although the new academic research in this area would be of some value, there is also a tendency for those who conduct research about the ethical dimensions of emerging technology to gravitate toward the more comfortable, even trivial questions involved, avoiding issues that might become a focus of conflict. The professional field of bioethics, for example, (which might become, alas, a model for nanoethics) has a great deal to say about many fascinating things, but people in this profession rarely say "no."

Indeed, there is a tendency for career-conscious social scientists and humanists to become a little too cozy with researchers in science and engineering, telling them exactly what they want to hear (or what scholars think the scientists want to hear). Evidence of this trait appears in what are often trivial exercises in which potentially momentous social upheavals are greeted with arcane, highly scholastic rationalizations. How many theorists of "intellectual property" can dance on the head of a pin?

One way to avoid the drift toward moral and political triviality is to encourage social scientists and philosophers to present their findings in forums in which people from business, the laboratories, environmental organizations, churches, and other groups can join the discussion. It is time to reject the idea there are only a few designated stakeholders that are qualified to evaluate possibilities, manage the risks, and guide technology toward beneficial outcomes.

Examples of technology policy steered by narrowly interested technical elites can be found in America's systems of medicine. For several decades, research and development have produced ever more exotic, high tech treatments that help propel costs of health care to dizzying levels. Following this path, according to the Word Health

Organization, the U.S. ranks only 24th the quality of medical care actually delivered to its populace.

For many decades, there has been a tendency in government funded research and development to exclude the participation of those who are the ultimate stakeholders—the general public. Citizens pay the bills for the work unfolding; they and their children and grandchildren will be the ones to experience the ultimate outcomes, good or bad.

Why not include the public in deliberations about nanotechnology early on in the process rather than after the products reach the market?

In that light, I believe Congress should seek to create ways in which small panels of ordinary, disinterested citizens, selected in much the way that we now choose juries in cases of law, be assembled to examine important societal issues about nanotechnology. The panels would study relevant documents, hear expert testimony from those doing the research, listen to arguments about technical applications and consequences presented by various sides, deliberate on their findings, and write reports offering policy advice.

It is possible that the news media would find these citizens panels a fascinating topic to cover. The active engagement of everyday folks in the shaping of public understanding of emerging issues and controversies in this area could make extremely valuable contributions to the articulation of issues, problems and possible solutions.

To begin, one might ask citizens panels to explore two highly relevant questions.

Will proposed paths for the military application of nanotechnology make us safer or not?

Would projected uses of nanotechnology in industry tend to create jobs or eliminate them?

There is now a lively research program within the National Science Foundation—Social Dimensions of Engineering, Science, & Technology—that funds experimental citizens panels of the sort I am describing. I would suggest that Congress build upon these fruitful experiments and specify (perhaps in the present legislation) citizens panels as one way to inform public debate about the societal and ethical dimensions of nanotechnology.

These days we often hear how important it is to be innovative in emerging technical fields. Here is a way that Congress could be truly innovative—creating ways for citizen stakeholders to join in the study and evaluation of new technologies.

Thank you for considering these ideas and suggestions.

BIOGRAPHY FOR LANGDON WINNER

Langdon Winner is a political theorist who focuses upon social and political issues that surround modern technological change. He is the author of *Autonomous Technology,* a study of the idea of "technology-out-of-control" in modern social thought, *The Whale and The Reactor: A Search for Limits in an Age of High Technology,* and editor of *Democracy in a Technological Society.*

Praised by *The Wall Street Journal* as "The leading academic on the politics of technology," Mr. Winner was born and raised in San Luis Obispo, California. He received his B.A., M.A. and Ph.D. in political science from the University of California at Berkeley. He is Professor of Political Science in the Department of Science and Technology Studies at Rensselaer Polytechnic Institute in Troy, New York. He has also taught at The New School for Social Research, M.I.T., College of the Atlantic, the University of California at Santa Cruz, and the University of Leiden in the Netherlands, and has lectured widely throughout the United States and Europe. In 1991–1992 he was visiting research fellow at the Center for Technology and Culture at the University of Oslo, Norway. During the spring semester of 2001, he will be Hixon-Riggs Visiting Professor of Science, Technology and Society at Harvey Mudd College in Claremont, California.

Mr. Winner is past president of the Society for Philosophy and Technology. A sometime rock critic, he was contributing editor at *Rolling Stone* in the late 1960s and early 1970s and has contributed articles on rock and roll to *The New Grove Dictionary of Music and Musicians* and *The Encyclopaedia Britannica.* At present he is doing research and writing on a book about the politics of design in the contexts of engineering, architecture and political theory. Another book, a collection of essays on technology and human experience, is also underway.

Mr. Winner's views on social, political and environmental issues appear regularly in Tech Knowledge Revue, published in the on-line journal "NetFuture."

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DEPARTMENT OF SCIENCE AND TECHNOLOGY STUDIES

April 9, 2003

The Honorable Sherwood Boehlert
Chairman, Science Committee
2320 Rayburn Office Building
Washington, DC 20515

Dear Congressman Boehlert:

Thank you for the invitation to testify before the U.S. House of Representatives Committee on Science on April 9th for the hearing entitled *The Societal Implications of Nanotechnology*. In accordance with the Rules Governing Testimony, this letter serves as formal notice of the Federal funding I currently receive in support of my research.

I received no federal funding directly supporting the subject matter on which I testified, in the current fiscal year or either of the two procceding fiscal years.

Sincerely,

Langdon Winner

Dr. Langdon Winner
Professor of Political Science
Department of Science and Technology Studies
Rensselaer Polytechnic Institute

Rensselaer Polytechnic Institute
110 8th Street | Troy, NY 12180-3590 USA
Telephone (518) 276-6574 | Fax (518) 276-2659 | www.rpi.edu/dept/sts/

Chairman BOEHLERT. Thank you, Dr. Winner. Ms. Peterson.

STATEMENT OF MS. CHRISTINE PETERSON, PRESIDENT, FORESIGHT INSTITUTE

Ms. PETERSON. Thank you, Mr. Chairman, and thank you to the entire Committee for taking on this very challenging topic.

There is a lot of confusion about nanotechnology. The term is used in two main—two different ways, primarily. The first is almost any technology a lot smaller than microtechnology. This is—this would include nanoparticles. This is happening today. There are issues here, and these are the issues that, for example, Dr. Colvin addresses. The second is a longer-term application. Nanotechnology is the ability to work at the molecular level to create large structures with fundamentally new molecular organization. This is more the type of nanotechnology that Mr. Kurzweil was addressing. Number one should be studied. Dr. Colvin's group and many others are available to do that, but the impact compared to number two will be—in comparison, will be relatively modest.

I am focusing now on the advanced nanotechnology. This is—it is basically a new way of thinking about physical matter. Today, you can have atomic precision at the molecular level. That is chemistry. Or you can have large complex structures. You can't have both at the same time. The goal is to get both at the same time so that you can have products of any size designed down to the atomic level.

How do you get there? First, this is an extremely ambitious goal. This is, as Mr. Kurzweil said, we are looking, perhaps, a couple decades out. You do it using systems of molecular machines. This is how living systems work. This new way of doing technology is inspired by living systems. You can picture how these systems would work as something like factories operating at the nanometer level including, for example, nanoscale conveyor belts and robotic arms bringing molecular parts together precisely, bonding them to form products with every atom in a precise design location. Again, very difficult, very challenging, tremendous momentum in this direction.

I am about to show you a couple of pictures. These are not artist conceptions. These are actual designs, which we believe either could be built as designed or something very like them.

[Diagram.]

This is a cutaway view. You are seeing the inside as well of a differential gear. You have differential gears in your cars, I am told, but this one is at the molecular level. You can see the individual atoms. Again, a design. We can't build this now, but we believe someday it could be done.

[Diagram.]

Another design, this is the tip of a robotic arm, a positioning device operating at the nanoscale.

What are the benefits of this level of technology? Mr. Kurzweil pointed at them. Medical; tremendous benefits here: being able to rearrange, restructure tissue at the molecular level could restore health regardless of a disease's cause. At the environmental—in the environmental area, which is the one that excites me, being able to build products with zero chemical pollution and being able to do environmental restoration at the molecular level is very exciting. The—we should be able to raise sustainable living standards, because this form of manufacturing is, in principle, very inexpensive, as living systems show us. And finally, the strong, lightweight materials that could be made this way may give us much lower cost access to space and space resources.

Is there a downside? There definitely is a downside. There is a potential for accidents with any powerful technology. Already, because there has been so much attention to this, and our organization certainly has been looking at this for 15 years or so, we already have safety rules drafted. They are on the Web. They are ready for critiquing. There is a private sector role here in cooperating and developing these safety rules.

This is a disruptive technology. There could be economic impacts, job transitions. We are going to need some education to help people make the change. There will be problems with lack of access to this technology, conceivably. These basic parts, gears, bearings, very simple—perhaps very simple motors, it is not clear you want these patented. Think of them as being the alphabet that you build on rather than something that you want to tie up, perhaps, in patents. Something to consider and look at.

The most challenging problem would be deliberate abuse and terrorism with this. One way around that would be rather than developing it in a secret program, would be open international R&D with broad participation and a parallel arms control effort. Some would argue that perhaps we shouldn't develop this technology. I don't think it is optional. It is clearly coming. Many countries and companies are on the pathway. To me, this looks inexorable.

What do we do about this? This is still controversial. Molecular manufacturing is controversial. The technical community has not yet done a serious feasibility study of this. We urgently need a basic feasibility review in which proponents and critics of the technology can make their technical case to a group of unbiased physicists. And that would be my one suggestion is to add something like that to the legislation.

Thank you, Mr. Chairman.

[The prepared statement of Ms. Peterson follows:]

PREPARED STATEMENT OF CHRISTINE PETERSON

First, I'd like to thank the Committee on Science for taking on the task of addressing the societal implications of nanotechnology. This challenging topic may emerge as the most difficult issue facing policy-makers over the coming decades.

Humanity's drive to improve our control of the physical world is intrinsic to our species and has been in progress for millennia. A vast international economic and military momentum pushes us toward the ultimate goal of nanotechnology: complete control of the physical structure of matter, all the way down to the atomic level.

Confusion about nanotechnology

Before attempting to address societal issues, we need to clarify which stage of nanotechnology is being examined. Today the word is used in two very different ways:

- Near-term nanotechnology: Industry today uses the term to cover almost any technology significantly smaller than microtechnology, e.g., nanoparticles. These new products will have positive and negative health and environmental effects which should be studied, but their societal effects—both positive and negative—will be modest compared to later stages of the technology.

- Advanced nanotechnology: Technology enabling broad control at the level of individual atoms: "The essence of nanotechnology is the ability to work at the molecular level. . .to create large structures with fundamentally new molecular organization." (ref 1) It is this stage of nanotechnology which will have major societal impact, and the remainder of this testimony will focus here.

Molecular manufacturing: the long-term goal

Advanced nanotechnology, known as *molecular manufacturing,* will give the ability to construct a wide range of large objects inexpensively and with atomic precision. It will take us beyond materials and devices to complex systems of molecular machines, inspired by—but in some ways superior to—those found in nature.

Molecular manufacturing systems can be envisioned as factories operating at the nanometer level, including nanoscale conveyor belts and robotic arms bringing molecular parts together precisely, bonding them to form products with every atom in a precise, designed location (ref 2).

It is important not to minimize the technical challenge of such a complex systems engineering project. Indeed, new tools must be developed before beginning a direct attack on the problem. Nonetheless, ongoing research is building the needed technology base, and will eventually place enormous payoffs within reach.

These prospects have been known since the first technical publication on the topic in 1981 (ref 3), and substantial thought has been devoted to potential societal implications of molecular manufacturing. Foresight Institute was founded in 1986 to maximize the societal benefits and minimize the problems expected from advanced nanotechnology.

Potential benefits of molecular manufacturing

Gaining molecular-level control over the structure of matter will bring a wide variety of positive applications (ref 4):

- **Medical uses:** Molecular machine systems will be able to sense and rearrange patterns of molecules in the human body, providing the tools needed to bring about a state of health, regardless of a disease's cause (ref 5).
- **Environmental applications:** Using molecular manufacturing techniques, it will be possible to construct our products with zero chemical pollution, recycling leftover molecules. Environmental restoration could be carried out at the molecular level, detecting and inactivating unwanted chemicals (ref 6).
- **Raising sustainable living standards:** Molecular manufacturing will be able to cleanly and inexpensively produce high-quality products using common materials (especially carbon, which is in excess in the atmosphere in the form of carbon dioxide) and solar energy (ref 6).
- **Low cost to access to space:** The strong, lightweight materials enabled by molecular manufacturing will greatly lower the cost of access to space and space resources, making their active use affordable for the first time.

These benefits should be attainable though the combined results of (1) a well-funded R&D program, (2) private sector efforts to bring down costs, and (3) public policy aimed at addressing the issues listed below.

Potential negative effects of molecular manufacturing

Powerful technologies bring problems as well as benefits, and advanced nanotechnologies are expected to bring problems of several sorts:

- **Accidents:** Any powerful technology—from fire to biotech—must be controlled to avoid accidents. In the case of molecular manufacturing, rearranging matter at the molecular level can either improve or destroy a system. Molecular machine systems able to build complex objects could build copies of themselves, possibly overdoing this activity from a human point of view, as bacteria do.

  An approach to the problem: This issue has been examined and a set of safety rules has been drafted for review; these are expected to evolve as we gain more knowledge about safety issues (ref 7). Implementation will require the cooperation of the private sector, and early endorsement of safety guidelines could ease public concerns about the technology.
- **Economic disruption:** Technological change continually disrupts employment patterns, but molecular manufacturing is expected to accelerate this significantly: once certain specific points of development in this technology are reached, very rapid change can take place.

An approach to the problem: Increase workforce flexibility through education and training.

- **Lack of access:** Excessive or incorrect patenting of fundamental machine parts at the nanoscale may reduce commercial competition and make molecular manufacturing products too expensive for many to benefit.

  An approach to the problem: Increase private sector competition by discouraging patenting of basic molecular machine parts needed by all companies doing molecular manufacturing. Consider using "open source"-style intellectual property protection for publicly-funded R&D so that this work is available to all (ref 8).

- **Deliberate abuse/terrorism:** Of the potential problems molecular manufacturing may bring, this is regarded as the most serious and most challenging to address. Three main areas of concern have been identified: (1) very rapid construction of conventional weapons, making traditional arms control more difficult, (2) totalitarian control of civilian populations by surveillance using nanoscale sensors, and (3) new weapons made possible by the technology, which can be thought of as "smart" chemical weapons.

  An approach to the problem: Encourage an open, international R&D program with broad cooperation by the democracies, including a parallel arms control verification project (ref 6). Improve today's chemical weapons arms control procedures.

Reducing risks from molecular manufacturing

Individuals and organizations with legitimate concerns regarding advanced nanotechnology have suggested delays in development, even moratoria or bans. While these reactions are understandable, this approach was examined over a decade ago and rejected as infeasible (ref 4). Today, both public and private spending on nanotechnology is broadly international. Expected economic and military advantages are driving a technology race already underway. If law-abiding nations choose to delay nanotechnology development, they will relinquish the lead to others.

Non-U.S. locations have at least three advantages in the nanotechnology race: (1) labor costs for scientists and technologists are usually lower, (2) intellectual property rules are sometimes ignored, and (3) the former "brain drain" of technical talent to the U.S. is slowing and in some cases reversing. The U.S. and other democracies have no natural monopoly in developing this technology, and failure to develop it would amount to unilateral disarmament.

In developing a powerful technology, delay may seem to add safety, but the opposite could be the case for molecular manufacturing. A targeted R&D project today aimed at this goal would need to be large and, therefore, visible and relatively easy to monitor. As time passes, the nanoscale infrastructure improves worldwide, enabling faster development everywhere, including places that are hard to monitor. The safest course may be to create a fast-moving, well-funded, highly-focused project located where it can be closely watched by all interested parties. Estimates are that such a project could reach its goal in 10–15 years.

Specific ethical considerations

A study of ethical implications of advanced nanotechnology would need to address at least these factors:

- The different kinds of nanotechnology and their likely windows of impact.
- A wide spectrum of different scenarios, including ones in which a significant molecular manufacturing R&D project is already in progress elsewhere.
- The potential consequences of "saying no" to the technology, as well as those of saying yes. These may be unevenly distributed; for example, those in poor countries might be hurt more by a delay—especially of environmental applications—than those in the U.S.
- In most cases, society does not "say no" or "yes" to a technology, but instead moves forward with appropriate controls. Ethical issues arise in defining the dimensions and consequences of such controls.
- To date the dialog around nanotechnology has been polarized, with only one viewpoint—near-term nanotechnology—being included in policy-making. A meaningful discussion of ethics and consequences requires us to ensure that a wide variety of opinions are represented in any downstream policy body or Presidential Commission on nanotechnology.

Bottleneck: Lack of feasibility review

While the basics of molecular manufacturing have been in the literature for over a decade, controversy still continues about the technical feasibility of this goal.

We urgently need a basic feasibility review in which molecular manufacturing's proponents and critics can present their technical cases to a group of unbiased physicists for analysis.

If we are in fact on the pathway to building molecular machine systems, with all the benefits and problems that implies, policy-makers need to know now in order to respond appropriately as this opportunity approaches.

The United States has a history of technological success in large systems engineering projects—it has been one of our primary strengths. But nanotechnology research is already worldwide, and there is no guarantee that the U.S., an ally, or other democracy will be the first to reach molecular manufacturing, and failure to do so would be militarily disastrous.

Such an ambitious R&D project requires, first, a decision to pursue the goal, and then substantial funding. Both of these are currently blocked by the lack of consensus on the technical feasibility of molecular manufacturing. Until this issue has been put to rest, neither a funded molecular manufacturing R&D project nor effective study of societal implications can be carried out.

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BIOGRAPHY FOR CHRISTINE PETERSON

Christine Peterson writes, lectures, and briefs the media on coming powerful technologies, especially nanotechnology. She is co-founder and President of Foresight Institute, a nonprofit which educates the public, technical community, and policy-makers on nanotechnology and its long-term effects.

She directs the Foresight Conferences on Molecular Nanotechnology, organizes the Foresight Institute Feynman Prizes, and chairs the Foresight Gatherings.

She lectures on nanotechnology to a wide variety of audiences, focusing on making this complex field understandable, and on clarifying the difference between near-term commercial advances and the "Next Industrial Revolution" arriving in the next few decades.

Her work is motivated by a desire to help Earth's environment and traditional human communities avoid harm and instead benefit from expected dramatic advances in technology. This goal of spreading benefits led to an interest in new varieties of intellectual property including open source software, a term she is credited with originating.

With Eric Drexler and Gayle Pergamit, she wrote *Unbounding the Future: the Nanotechnology Revolution* (Morrow, 1991), which sketches nanotechnology's potential environmental and medical benefits as well as possible abuses.

Christine holds a Bachelor's degree in chemistry from MIT.

FORESIGHT INSTITUTE

Preparing for nanotechnology

April 9, 2003

The Honorable Sherwood Boehlert
Chairman, Science Committee
2320 Rayburn Office Building
Washington, DC 20515

Dear Congressman Boehlert:

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Sincerely,

Christine Peterson

Box 61058 • Palo Alto, CA 94306 USA • Phone 650 917-1122 • Fax 650 917-1123
inform@foresight.org • www.foresight.org

DISCUSSION

Chairman BOEHLERT. Thank you very much. Thank all of you. Let me ask the entire panel. We will go in the order of your presentation. What do each of you think is the most serious, legitimate concern about nanotechnology? Keep in mind, we are a society where there are some people who still think putting fluoride in water is a plot to undermine the youth of America. But what do you think is the most serious, legitimate concern about nanotechnology, and how would you construct a research program to investigate it? Mr. Kurzweil.

Mr. KURZWEIL. Christine Peterson mentioned that there is a near-term and a long-term. They are really two different fields, and the era we are on now is nanoparticles. These are a bit more limited in their benefits but still will be measured in billions of dollars. They are more benign in their dangers. They do reflect a new type of safety concern in that these particles are small enough to get inside our tissues, cross the blood/brain barrier. Of course, it is not the first time that new materials, even at that scale, can get inside the human body.

I think we need some strengthening of existing regulation to look at this new concept. But I would say the existing scheme of regulation we have on environment and health should be sufficient, but it does need to deal with these new types of materials that we will be coming into contact with.

The real controversy in nanotechnology has to do with self-replication. I mean, self-replication is the source of the greatest danger in the world. Atomic weapons have to do with self-replication. Disease is self-replicating pathogens. Cancer is self-replicating cells, and the biggest concern we—and biotechnology, we are concerned with bioengineered pathogens. That actually is the biggest concern in near-term technology, although it is outside the view we are talking about. And the biggest, most controversial concern about nanotechnology is when we have the advent of self-replication.

Now why would we have self-replication? It is really necessary in order to scale up from these tiny, atomic sized devices to something that is physically large. You are going to need some self-replication to get the scale to make this technology viable. Well, self-replication gone awry is a cancer, and if you get a cancer of non-biological materials, it could be very threatening. I proposed here, in my written testimony, some ways that we can deal with that. Christine Peterson's organization, the Foresight Institute, has spent over a decade developing ethical standards that I think will be—and also technological strategies that will be effective at preventing accidental release of self-replicating nanotechnology.

The concern with intentional abuse is much more serious, and there I would point us to the success we have had in software viruses, which is another self-replicating pathogen. And there is really no single strategy. Come up with a strategy and then someone can defeat it, and then we have to defeat the new, more sophisticated offense. We have to stay a step ahead. I would say the biggest advice—the most important advice I would give is we—society needs to put far greater resources into actually developing the defensive technologies and—because we are not on—right now on the threshold of self-replicating nanotechnology. We are on the threshold of self-replicating biotechnology.

Chairman BOEHLERT. Okay.

Mr. KURZWEIL. And a terrorist, a bioterrorist does not need to put his innovation through the FDA, whereas the scientists we are relying on to defend us are—do have—are slowed down by the regulatory process at every step. And it is hard to even imagine how you could put a biodefense through the FDA, because it would be unethical to test these on humans. I think how we deal with bioengineering actually will be a good test case for nanoengineering.

Chairman BOEHLERT. Dr. Colvin, do you have some thoughts on that?

Dr. COLVIN. Yeah, I am glad you asked that question. Clearly from my testimony, I believe that when you think about societal impact, you are going to have to play a game of technology forecasting. I believe that if we had infinite resources in this body, perhaps we could do everything, but we need to make some very tough choices about where we focus societal impact, what kind of term you look at. I believe that the near-term issues with environmental health and safety are significant. The knowledge base is not there, and if those are not handled well, we will call into question the ability of these longer-term goals to survive. We all know in biotechnology how problems in one area can taint the entire discipline. So I believe these near-term effects are significant, and I disagree that substantial resources are going into the issue—the question, so I see that as the issue.

And just—on the self-replicating machines, the technology forecasting is essential here. How do you know what nanotechnology will do? I look to the guidelines of the National Nanotechnology Initiative, which set forth very specific technological challenges, not one of which includes self-replicating robots or machines. It is a very controversial topic. The majority of academic nanotechnology researchers feel that there are substantial problems with that particular future being envisioned. I would never say nothing is ever possible, but in light of the very near-term consequences that we are currently looking at, it makes more sense to focus the research dollars on those topics at this point.

Chairman BOEHLERT. Thank you very much. Dr. Winner.

Dr. WINNER. Yes, I would point to a general issue that covers a number of problems that people have talked about, which is the possibility of irreversible harm. As a general matter, I think technology should be Judge Superior if the consequences of their use are reversible. And this suggests we need a kind of research strategy here that would enable us to do the kinds of applications and experiments in a controlled, bounded way rather than simply releasing them into the world and then see what happens.

In that regard, I would object to Mr. Kurzweil's comparison analogy between computer viruses and, let us say, self-replicating machines in the environment. The computer viruses exist within certain kinds of systems, but we are proposing to take the new materials and new processes of nanotechnology and release them in ways that would ultimately enter our bodies and the biosphere. So I think we are going to need some very clever and careful ways of testing on a limited scale the way these things work, to try them out in a way that if problems arise, then you won't be stuck with a Pandora's box.

Chairman BOEHLERT. Thank you very much. Ms. Peterson.

Ms. PETERSON. First, I would like to say, excuse me, I agree with Dr. Colvin that more funding is needed for these near-term effects of current nanotechnology. I don't—I would certainly not argue that enough is going there, so let us try to get that up.

Chairman BOEHLERT. Well, just let me observe. You know, the National Academy of Science pointed out that the National Science Foundation explicitly included societal implications in its solicitations for nanotechnology research during fiscal year 2001. Few proposals were submitted and none were funded. And one of the things you are suggesting is that we fence off a certain amount of money, maybe five percent, and mandate that that go for this type of study.

Dr. COLVIN. Yes, I think that you have hit on an essential issue.

Chairman BOEHLERT. All right. Thank you. I know the red light is there, but I want the panel to have the opportunity to answer this one question, and then I will go to Mr. Honda. Would you finish, Ms. Peterson?

Ms. PETERSON. Yes, so—and I would also agree with Dr. Colvin that the molecular manufacturing scenario is highly controversial. However, I can tell you that I have been tracking this for over 20 years, and I—there has not been any substantive technical argument against this. Believe me, I am looking. If I ever find one, I could go do something else, okay. So I would reemphasize, I think we need to do a feasibility study of the type that I suggested. And the reason is that the fear and the hope regarding this long-term nanotechnology is spilling over onto the near-term nanotechnology, and that is going to be a problem for near-term possibilities. So if we can allay those fears, the near-term nanotechnology will also benefit.

Thank you.

Chairman BOEHLERT. Thank you very much. Mr. Honda.

Mr. HONDA. Thank you, Mr. Chairman. And I think that this—the line of questioning discussion is very important, and I would support something like setting aside funding for—specific to that activity.

You mentioned—we are talking about advisory committees and external and internal advisory committees. Could you share with us how you think we can make the input of an advisory committee stick or make it important? I mean, a lot of times we get input and it gets lost in the wash. Would you share with us some of the ideas you may have? Dr.—Ms. Peterson, you have thought about this for some time. Maybe you have some ideas, and then we will hear the rest of the panel.

Ms. PETERSON. In this area, I think nanotechnology is an—is basically an engineering field. The goal is to achieve certain technical results. And I think one thing that has been missing, perhaps, in the way we have been coming at it as a nation has been a focus on engineering teamwork and putting together specific projects with very clear technical goals. And I know the NNI is moving in that direction, but I think we need to move much more. So I think if there could be an advisory committee that puts together very clear technical goals that could be fed somehow into the legislation, that might be helpful.

Dr. WINNER. I would be careful to place these questions solely in the hands of scientific and engineering elites. We did that with nuclear power where the essential questions took decades to surface, questions about the cost of the plants, questions about the safety of the plants, questions about nuclear waste disposal. When these questions erupted powerfully in the 1970's and 1980's, the social coalition of support for nuclear power collapsed. And what I fear is that if we say, well, the main voices that matter here are the scientists, the engineers, the entrepreneurs and so forth, we are not going to include society as a whole. We are not going to include the public in the process and which eventually ordinary folks are going to have to decide whether this is a technology—or these are technologies they can support or not. I would say open up the process more broadly and early on.

Dr. COLVIN. As far as the question about the advisory panel, I believe that in the particular case of societal impact is—the point I tried to make is that you are swimming upstream in many ways to get both scientists and engineers and even social scientists and funding agencies engaged. So I believe the advisory panel will serve an important role in looking over how that research is going. I would suggest that they be charged, certainly, with the process of classifying research projects.

It can be a little tricky to decide if somebody is looking at a brand new way of desalinating water, if that is an application or an environmental implication. In my mind, that is a technology development, not a health and safety issue. So those kinds of issues, I think, are something an advisory panel can do. I agree completely that we need to broaden the base. Advisory panels must include social and environmental scientists, but they absolutely also must include science and technologists.

I believe that in the area, scientists and engineers have changed a lot since the '70's. This is really a great moment to train, especially our younger generation of scientists and engineers, to think much more broadly about applications. And I think that they are ready to do that. They are ready to recognize they have to engage the public and a much broader context for their work. And I believe the advisory panel will be a snapshot of a group of people with diverse backgrounds. And hopefully those are the types of profiles we will see also when the research grant is funded.

Mr. KURZWEIL. I agree with Dr. Colvin that you need to have both ethicists and representatives of the public interest as well as scientists. Representatives of the public really can't deal with the issues unless the scientific implications are understood, and these generally involve difficult scientific and engineering issues. I think it would be reasonable to have any proposal be required to address potential dangers, environmental impacts, impacts on health, as we sometimes do with environmental impact, but to specifically address these emerging safety issues as these technologies get more powerful.

And just to respond to something that Dr. Winner said earlier, it is nobody's proposal to release into the natural environment self-replicating entities that are not biological. I mean, that is specifically the sort of cornerstone of the ethical guidelines that the industry has come up with. And a lot of the specific technical strategies are designed to prevent that from happening.

Chairman BOEHLERT. Thank you very much. The gentleman's time has expired. The distinguished Chairman of the Subcommittee on Research, Mr. Smith of Michigan.

Mr. SMITH OF MICHIGAN. Mr. Chairman, thank you. I am glad to see many of the panelists sort of relate some of the problems that we have had in biotechnology and the slowdown of that research because of rhetoric that may be more based on emotion than scientific fact. And certainly, Mr. Winner, we want to bring in a broader evaluation to make sure that we don't stall the good research that can be accomplished through nanotechnology. And we still have that problem hanging out there with biotechnology that, in many areas, we have slowed down.

Help me understand a little bit some of what you see just sort of in your vision of some of the potential for nanotechnology, and just go down the role. And what are some of the possibilities out there, starting with you, Mr. Kurzweil?

Mr. KURZWEIL. Well, probably the most exciting is to build small devices that can go inside the human body, actually travel inside the bloodstream and perform therapeutic and diagnostic functions. Now that might sound futuristic, but we are actually doing that today. There are four major conferences on something called BioMEMS, Biological Microelectronic Mechanical Systems, and that is not quite nanotechnology, but these are tiny devices that go inside the bloodstream. One scientist actually cured type I diabetes with a nanoengineered device that has seven nanometer pores that lets insulin out, blocks antibodies, and actually cured type I diabetes in rats. And this same mechanism—there is no reason to believe this same mechanism wouldn't work in humans.

Ultimately, when we can design devices that are very small, we can go and scout out pathogens, destroy cancer. One scientist, Rob Freitas, has designed replacements for portions of our bloodstream that would overcome blood diseases and greatly extend human health and longevity.

Mr. SMITH OF MICHIGAN. Well, save some for Dr. Colvin.

Dr. COLVIN. Did you mean by possibilities our—the wonderful things that can happen or kind of a more of a discussion of some of the negative, you know, the implications that are——

Mr. SMITH OF MICHIGAN. Well, I think that is important, too.

Dr. COLVIN. Yeah.

Mr. SMITH OF MICHIGAN. And Mr. Chairman, you know, maybe we need some of—skeptics along with the scientific——

Dr. COLVIN. Okay. All right. I will add what——

Mr. SMITH OF MICHIGAN. I don't want you to take the role of a total——

Dr. COLVIN. Right, because I—much of what we do in my center is actually biomedical research using nanoparticles. And I would echo the previous comment and that already are small particles actually made from the bottom up now are multi-functional, can hunt down cancer cells and kill them if you shine light on them from the outside. That is something that Dr. Jennifer West, in our center, has pioneered. So it is really amazing what small particles can do inside of our bodies. They can—because of their extremely small size, they are much, much smaller than a red blood cell, their access to biological environments is amazing. And we can leverage that in generating entirely new ways for treating disease. And that is actually already happening.

The flip side of that is that because of their rather unfettered access all over our body, the body can interact with them in unusual ways, and that is already becoming part and parcel of our medical research. So what that means to me is that we are in a situation, especially when we find the wide use of nanoscale particles, particularly in cosmetic applications, in a situation where consumers are exposed to them unintentionally every day. And that is a situation where we have to, I think, step back and say, "Are the benefits of a cosmetic application necessarily worth, perhaps, some of the issues we may face with their access to the body and long-term effects?"

Unfortunately, very little is known. The societal impact research from NSF is limited to only social scientists. No environmental impact research, with the exception of the small amount of—that we do, comes from societal impact. So my warning to you is with societal impact, that will be interpreted as social science, so if the environmental part is something you want to stress, you are going to need to say that.

Dr. WINNER. Yeah, Mr. Smith, one thing that interests me about the way this research is being justified is that we have, in my view, powerful tools that are going out looking for uses. So you have a list of all of the things that nanotech might do. I think, perhaps, a more fruitful approach for a national budget would be to say, "What are the Nation's greatest needs? What are our greatest problems? How might research address those issues?" Nanotechnology, right now, is, I guess, in the hundreds of millions of dollars in research. One can see this being ramped up, you know, powerfully in decades to come.

And we have this, what I would call a kind of opportunistic logic of technical choice. "Let us try this. Let us try that. Let us do what these entrepreneurs want or these researchers want." One thing that bothers me about this is the kind of opportunistic logic that reverses what we normally expect is the relationship between ends and means, where we first clarify our ends, saying, "These are our basic priorities. Here is what American society needs." And then we go out looking for means that might satisfy those ends. In nanotechnology, as I hear it consistently defined, what we have is a process in which the tools go out looking opportunistically for things to do. That bothers me. I think it should bother you.

Ms. PETERSON. Regarding the potential benefits, we have covered the medical ones. I will just touch on three more. Environmental benefits, the potential of being able to make our products with zero chemical pollution and do environmental restoration all the way down to the molecular level. The second one would be how are we going to bring living standards up in the poor countries without having environmental difficulties? And that has been a tension for a long time. The goal here would be if we can make our products cleanly and inexpensively, we might be able to accomplish that difficult goal. And third, we have seen not too long ago the disastrous consequences of materials problems in our space program. With nanotechnology, we should have much stronger, lightweight materials and perhaps finally make space resources and space activities affordable and safe.

Chairman BOEHLERT. Thank you very much. The gentleman's time has expired. Mr. Miller.

Mr. MILLER. Thank you. We had an earlier hearing on nanotechnology. And the gist of it was that we were not really ahead, perhaps behind several other nations that were involved in nanotechnology research. I can't recall the list: the EU, obviously, I recall China, I think Israel, perhaps Korea, maybe India. But in any case, we did not have the—kind of the lead in the—in research in this area that we have had in other great advances in the last generation. What is going on in the other nations doing nanotech research on these issues? Are they pausing over ethical concerns or pausing over safety issues, environmental hazards? Are they setting up citizen panels? What are they doing? Anything?

Mr. KURZWEIL. I don't think the ethical concerns are slowing down nanotechnology yet. Some of the activist groups that have gone after genetically modified foods are now turning their attention on this issue, but so far, it is really in the discussion stage. Most of the research is in diverse areas, and is experimental. It is not really being slowed down a bit. It is a very diverse activity.

Another exciting area, which is really going on around the world, is in electronics, developing three-dimensional molecular circuits, which can then continue the exponential growth of computing beyond the flat integrated circuits governed by Moore's Law. And that actually—most of that research has been here with some in Europe and Israel, but we have a lead in that particular technology.

Dr. COLVIN. Last year, I participated in a workshop in Italy on societal impacts of nanotechnology with many international participants. What was clear to me is that the European funding agencies take particularly the near-term consequences quite seriously. They come from a culture where basically concerns about genetically modified organisms or some of the mistrusts between scientists and the public is quite severe. So they are actually in the stage this year of ramping up significant funding. I don't know the exact numbers, I could provide them, to get put particularly into the issues of environmental and health impacts.

And in fact, in England, this has received—noted the highest levels of the government because of the activities of some of these non-governmental organizations. So they have been quite effective, particularly in Europe, of drawing attention to this issue. And I believe our European colleagues will be paying very close attention. And there is much more substantial discussion, for example, of regulation in Europe than there is here.

Dr. WINNER. I can't speak to the question of, you know, whether the United States is ahead or behind in specific areas. But your question suggests to me that in a global economy and global science and technology, with—these kinds of societal and ethical issues we are talking about today really need to be addressed globally as well, internationally. And I think one thing that people that are interested in this area should begin to explore is the creation of new institutions, trans-national institutions in which these kinds of research, deliberation, debate, and attention to issues could be pitched for attention.

Ms. PETERSON. I think we can expect to see these issues of societal implications being addressed. As Dr. Colvin said, in Europe, they are probably ahead of us. Here, we are ramping up, but there is substantial activity in Asia in nanotechnology and Japan and in China and in other countries. And I would be surprised, myself, to see an organized effort there. Maybe the other panelists can comment on that, but I think it is—in Asia, it is full steam ahead, and I think it is worth keeping an eye, for example, on China, where the number—the last number I saw for China was 300 million U.S. dollars equivalent. And keep in mind that the cost of scientists there is much lower. And so when you look at that number, you have to put in the multiplier effect, and so we may see tremendous advances coming out of China over the decades to come. And we could be surprised.

Mr. MILLER. Very surprised at how much the technology comes out of China?

Ms. PETERSON. Yes, China could, yeah.

Mr. MILLER. But if we were the only nation in the world—well, there may be some race at the bottom in their—in concern for safety and ethical——

Ms. PETERSON. I think yes. I think if there is nanotechnology research being done in countries that, perhaps, don't have our level of safety concerns, we might want to keep an eye on that.

Chairman BOEHLERT. Thank you very much. The gentleman's time has expired. Actually, you have two seconds left.

Mr. MILLER. I will yield back the balance of my time.

Chairman BOEHLERT. Thank you very much. The distinguished Chairman of the Subcommittee on Space, Mr. Rohrabacher.

Mr. ROHRABACHER. Am I the only one who is skeptical of the social sciences here? I don't know. I get to be the proverbial skunk at the lawn party.

Chairman BOEHLERT. You are not out of character.

Mr. ROHRABACHER. I mean, this sounds like to me you are putting all of the sociology and literature majors in charge of defining the goals of the engineering and, you know, science majors. I don't know what your experience in college was, but you know, I wasn't the one who wanted to trust the sociology majors with those type of decisions. Is that what I am getting here?

Dr. COLVIN. Do you want me to take—yeah, I will jump on that one.

Mr. ROHRABACHER. Okay. Please do.

Dr. COLVIN. Yeah, I think—so as a member of the nanotechnology community as scientists and engineers, it is strange to say, "Okay, we are going to—social scientists will receive substantial funding to evaluate our technologies." I think that we are all very open and believe that only an economist, for example, or an anthropologist could really figure out how, if you give very small palm pilots to, you know, third world countries how that might disrupt their culture. That is not something I can do.

But where we really find significant issues is when those same groups do their technology forecasting. So if they make an assumption that they are going to study some technology, that is what I believe you have to leave to the nanotechnology establishment is to decide what are the real issues? What are the technologies that exist? What are the specific things we are working towards? So that when we get partnerships with our social scientists and environmental scientists, they focus on the issues that actually are—matter to the groups that are the most closely related to the work. So I agree with your perspective, to some extent. But I believe the consequences research can't be done by nanotechnologists.

Mr. ROHRABACHER. I think what we are talking about here is——

Dr. COLVIN. Right.

Mr. ROHRABACHER [continuing]. Injecting bureaucracy into the sciences. I mean, you know, my experience is that you have got—you know, bureaucracy is the most effective method ever devised of turning, you know, pure energy into solid waste. And——

Dr. COLVIN. Well——

Mr. KURZWEIL. If I could interject one thought, which I think builds on something Dr. Colvin said, if you look at how things have gone with GMOs that has not gone well, and it is not apparently a scientific issue. It is a political and cultural issue. It is certainly a deeply cultural issue in Europe, and so it requires people with that kind of background. If we want to avoid——

Mr. ROHRABACHER. Are we assuming the nuts aren't going to be the ones on the panel?

Mr. KURZWEIL. Well, if we want to avoid that kind of disruption and have the benefits of these technologies go smoothly, avoid the peril, and avoid, you know, being sidetracked by these kinds of political and cultural issues, then we need people with that background to help us guide the technology.

Mr. ROHRABACHER. Let me be a—the skeptic again and—with what you are saying that—I mean, I really appreciate your engineering skills, and here we are. I mean, the—here is the non-scientist over here talking to the scientist about how you organize a structure, social structure, so that you can get your job done. I will tell you that it—when you are—if you set up these panels, you are going to have more quagmires rather than fewer quagmires, because you will have been giving—you will give a forum to the very nuts that you are trying to overcome in Europe and etcetera, especially when people talk about global panels, for Pete's sake.

Mr. KURZWEIL. But it may be better a panel and a lot of public discussion than the kind of complete breakdown of GMOs that we have seen in Europe.

Mr. ROHRABACHER. Well, maybe a—I will have to say that I certainly respect your opinion on the way engineering works and the way your scientific research works. I don't necessarily think that that is where we get our advice on how to create the social system that will permit your science to work best. I don't know if that made any sense at all, but that is—I said something in there.

Mr. KURZWEIL. It made a great deal of sense to me.

Mr. ROHRABACHER. All right. Let me just——

Mr. HONDA. Could we have one quick comment from Mr. Winner?

Mr. ROHRABACHER. Oh, yeah. Please.

Dr. WINNER. Yeah. Scientists can tell you the knowledge required to make these things work. Engineers can tell you how to make them work in practice. What neither of those groups really can do, except to perform their own roles as citizens as well, is what these technologies will mean to people when they enter the world of practice when they enter the environment. You talk about sort of multiple quagmires. In my view, that is probably inevitable to occur. And what you want to have happen is the most open, rational, critical, many-sided debate possible so that society can sort through not only how things work, but what they mean to us.

Mr. ROHRABACHER. I am just afraid that you are talking about setting up a situation where scientists in the physical hard sciences are going to be doing their work, coming up with terrific things like nanotechnology, and so these sociologists say, "Well, it has got to go through this buffer, this filter first before it can get to the public." You know, people have claimed to believe—claimed to have, you know, a fundamental knowledge of what the public interest is, you know, be very suspicious of giving them power, because they really think they know, and they might not.

Dr. WINNER. Well, that is why I have suggested we try, in this kind of work, to establish a voice for ordinary folks, citizens panels, who can look at the evidence, listen to the different points of view, and then offer their own ideas about what this is all about.

Mr. KURZWEIL. I would distinguish between dialogue and debate on the one hand and regulation on the other. And I think you are concerned about undue bureaucracy and regulation, which I share. But a lot of open debates and dialogue, even if some of it is not well grounded is ultimately going to be helpful to get some of the issues out so they can be addressed.

Mr. ROHRABACHER. Okay. Thank you.

Chairman BOEHLERT. Thank you very much. Mr. Sherman.

Mr. SHERMAN. Thank you, Mr. Chairman. I want to apologize, because I have got hours of things I want to talk about and only five minutes. So I am going to raise a bunch of questions and ask you folks to respond in writing, but I am going to do something else and that is invite you, or whichever of you might be free, to lunch. And perhaps a few of my colleagues will join us when they find out I am buying. I want to respond to the distinguished Chair of the Space Subcommittee that long before his Subcommittee authorized the programs that took us into space, the poets made us want to go there. And it is good to have the societal elements or, as he would abbreviate the term "nuts", talking to the scientists at an early stage in this process rather than wait until toward the end.

I commend the panel for focusing on the fact that one of the things nanotechnology may bring us is new orders of intelligence, whether that is through genetic engineering, perhaps at the nanotechnology level, or non-organic nanotechnology, or some combination. First I would point out that intelligence is the most explosive thing in the universe. There are those who think that fusion is the most explosive thing, except you realize intelligence gave us that fusion. Less than a decade—there was less than a decade between when Einstein wrote to Roosevelt of the possibilities of nuclear explosions and when we had to develop a nuclear, nonproliferation regime. And now we are engaged in regime change as part of that regime.

You know, Secretary Rumsfeld is in the armed services room briefing many of our colleagues on what is going on. Arguably, he should be briefing them in this room since his entire enterprise is described as a technology control project, that is making sure that the wrong people aren't doing the wrong kinds of science. So those who believe that only fools want to explore the idea of controlling and guiding science, you should talk to our men and women in uniform who are guiding the Iraqis to less science in some small aspect of their national life.

About 100,000 years ago, we saw the last increase in intelligence when Cro-Magnon greeted Neanderthal. Perhaps the first thing a Neanderthal said upon looking at Cro-Magnon is, "Is that us?" And I don't know. And we may be looking at new entities and wondering whether the next intelligence is our prodigy or our competitor or a bit of both. The—you have pointed out that we are going to see massive increases in the spread of knowledge and technology, and I am confident that humans will be better at curing those things that can be cured by intelligence. If SARS emerges 20 years from now, you science folks will give us a cure in weeks instead of years.

But there are problems caused by intelligence, like the fact that we can bombard nuclear atoms—or rather uranium atoms. And those problems will probably also increase, since their cause, human intelligence, increases. I want to commend Dr. Colvin for her pointing out that perhaps we ought to spend five percent of the budget on sociological research. I am sure Ms. Peterson was facetious when she suggested that that go exclusively to an impartial panel of physicists. And I think that Dr. Wiener—I think——

Dr. WINNER. Winner.

Mr. SHERMAN. Oh, am I pronouncing your name right? Winner. Winner. I forgot my reading glasses.

Chairman BOEHLERT. That is a New Yorker.

Mr. SHERMAN. Well, I believe that if you build a better mousetrap, the world will beat a path to your door, even if that world is a world of mice. And I think that as this technology develops, many paths will be beat to many doors. The question is whether the five percent of the budget that we hope to put into societal research will bear fruit. Mr. Kurzweil, I believe you have written that it is roughly 30 years between now and when we get a nonbiological intelligence that surpasses human intelligence and have suggested that that occurs by reverse engineering the human brain. Since I am out of time, I am going to ask each panelist how many years they think it will take any of the branches of nanotechnology to give us an intelligence that surpasses any known human intelligence. Just shout out a number of years, and make sure it is longer than anyone will hold you to account for, because we will forget your answer in less than a decade.

Mr. KURZWEIL. Well, 26 years.

Dr. COLVIN. 45.

Dr. WINNER. Actually, I hope never. One of the concerns about nanotechnology and science and engineering on this scale is that it is plowing onward to create a successor species to the human being. I think when word gets out about this to the general public, they will be profoundly distressed. And why should public money be spent, I would wonder, to produce an eventual race of post-humans? Perhaps this needs wider public debate.

Mr. SHERMAN. That is pretty much how we spent the last five minutes. Ms. Peterson.

Mr. KURZWEIL. If I could just suggest, since it came into the discussion, we already have people walking around who have computers in their brains who have Parkinson's disease or hearing disabilities or a dozen different neural implants. We have artificial augmentations or replacements of almost every body system, so the ultimate implication of these technologies will not be a successor species but really an enhancement of our human species. I would define the human species as that species that inherently seeks to extend our own horizons. We didn't stay on the ground. We didn't stay on the planet, and we are not staying with the limitations of our biology.

Mr. SHERMAN. I hope you are free for lunch. Ms. Peterson.

Ms. PETERSON. Well, I will say 25 to 30 years and express my surprise that this question would come up here and also say that these kinds of things are labeled science fiction. I—my work is often labeled science fiction, but I point out that if you look ahead 30 years and what you see sounds like science fiction, you might be wrong. But if it doesn't sound like science fiction, you are definitely wrong.

Chairman BOEHLERT. Thank you very much. The gentleman's time is expired. Let me note, once again, that Mr. Sherman has offered to buy lunch. And following this hearing, those who want to beat a path to his door are invited to do so.

Mr. WU. Mr. Sherman, that was to the entire audience, was it not?

Mr. SHERMAN. Except for those from Oregon.

Chairman BOEHLERT. The Chair is pleased to recognize the Vice-Chairman of the Full Committee, Mr. Gutknecht.

Mr. GUTKNECHT. Thank you, Mr. Chairman. Some of the questions that I was going to ask have already been asked, and I want to thank you for coming here today. I think this is sort of the beginning of what ultimately will be a big national debate. Coming from an agricultural area and also serving on the Ag Committee, I am concerned with what has happened in the whole debate about genetically modified organisms. And sometimes I think you can help as scientists to put this in some historical context. The GMO's best example is we have been modifying the genetics of plants for a very, very long time. I mean, we didn't just wake up one day and find tomatoes. Actually, the American Indian bred up the tomato plant that we know today. The same is true with what we now know as corn.

So this has been going on for a very long time, but all of a sudden, in the last 20 years, there is at least an element of the scientific community that has decided that we can't take any risks. There is no risk that we should take. And I like to remind scientists and my colleagues that it is not the statue of security that sits in New York Harbor. And our ancestors did not get to the great river, the Mississippi, and say, "You know, that is a pretty wide river. I guess we are going to have to turn around and go back." You know, there is something about being an American, and the same is true with space flight. You know, if we would have done the analysis and say, "You know, if we start putting people in space, some people are going to die. I guess we can't do that."

You know, I think we have to put all of this in some kind of context. The bottom line is we are going to move forward, it seems to me, with nanotechnology. That is going to happen. Now our European friends may, you know, sweat and curse and say we are being imperialistic or whatever, but it is going to go forward. The question is, can we do it in a moral way. I think there is a moral question here, and I think we have to begin to deal with that. But I want to come back to what I think is the fundamental question about genetically modified organisms. And that is that the people who developed them did a fabulous job of selling them to our farmers. They did a miserable job of selling the benefits to the consumers. And I wonder if any of you want to comment on that.

Dr. COLVIN. I will take that one. I have looked really closely at the GMO situation. I think that that is an excellent example of why public education is so important. It is clear that, as a scientist, I can not, and I don't think it is my place, to judge the risk benefit of any technology I develop. That is actually the policy makers' and the public's place. But it is up to me to provide the hard data, and so that is what I work towards. But I agree completely. As we enter into the nanotechnology realm, we have to point out when we have proponents saying, "Oh, my gosh, something might cause cancer," to point out very clearly that we already know that we can cure certain types of cancer in animals with nanotechnology. I think it is—you present to the public the benefits, they will make the right decision, especially in this country.

Mr. KURZWEIL. I am just—I would agree with your concern, but it disturbs me to see countries like Zambia and Zimbabwe reject vitally needed food aid under pressure from European anti-GMO activists. And I think we have a real consensus on this committee, despite some of the different perspectives that we come from, on substantial forums and analysis and debate and dialogue and review of these issues by interdisciplinary groups of people and real funding to do that, not bureaucracy and regulation, but open dialogue and exploration to really avoid some of the irrational and emotional reactions that have stymied GMO.

Dr. WINNER. Yeah, technologies are not only material inventions; they are also social constructions. I have tried to argue that the final stage in the matters of sort of social exceptions comes when the people themselves who are going to use these things say, "Yes, we like it. We can build this into our lives." Very often in recent times, people have said, "No, we don't want this." Right. They do it for reasons that seem significant to them, well grounded to them. We may look and say, "Oh, you are being irrational. You have a defective culture. Why don't you see the things the way we do?" And I think that attitude is going to be going forward extremely destructive.

What we need to do is to look more closely at the sources of doubt and resistance and say, "Well, what is on these people's minds?" Very often, the way people view risk, for example, in society, has to do with the way of life in which they are deeply involved. And they see technologies entering in, posing a threat to their livelihood, posing a threat to their system of meanings, including the religions that they have, and saying, “Well, wait. We are being rushed off in a direction that we are not comfortable with.” And I think faced with that kind of message to say, “Well, just look at the science and all of your problems will be solved,” is not going to be actually a very workable approach.

Ms. PETERSON. I think——

Mr. SMITH OF MICHIGAN [presiding]. Very briefly, and then we will move on to Mr. Bell.

Ms. PETERSON. Just to agree, I think rather than take the societal implications money and put it all into, perhaps, academic social science research, what I am hearing, I think, and what I agree with is broad public discussion reaching out, actually, to the people themselves. Because I think as Dr. Colvin pointed out, at least the American people, I think, if they are—if they feel informed, tend to reach to the right decisions. Also—another thing that would help would be for the research itself to be both open and international.

Mr. SMITH OF MICHIGAN. Just—it seems to me, before we move to Dr. Bell, that there are always going to be those groups, though, that embrace the precautionary principle defined as zero risk that are always going to be out there questioning the advancement and any research that is less understood. And Mr. Bell, and I assume that you are going to really direct tough questions to Dr. Colvin. Is—am I correct that you are working in his district?

Mr. BELL. Just a bunch of softballs, Mr. Chairman. Thank you. I—Mr. Chairman, I want to begin by saying I think this hearing demonstrates why it is so important that we be having this debate now rather than later. As Dr. Winner properly—appropriately points out and accurately points out in terms of nuclear energy, many of the problems were raised after the fact. We have seen the same thing with stem cell research. We know that there are going to be societal and ethical questions raised. It makes all of the sense in the world to be proactive and be addressing those questions here on the front end rather than on the back end to see if the questions can be addressed.

And yes, I am very glad to have Dr. Colvin here. I don’t think that I have succeeded at a single Science Committee hearing in not mentioning Rice University. And today will be no exception. The shameless self-exploration will continue, and she is also joined by Dr. Kristen Kulinowski, and I have been working with Rice to learn as much about this particular subject.

Mr. SMITH OF MICHIGAN. And your time is——

Mr. BELL. I will stop. If we can listen to Mr. Rohrabacher that long, you can certainly listen to me this long. I think that the Center for Biological and Environmental Nanotechnology at Rice is somewhat unique in that it is the only NSF funded center studying the environmental and health impacts of nanotech. And it is unique in that it claims to characterize the unintended consequences of nanotech, particularly in the environmental area, but it is also looking at some of the societal questions. And Dr. Colvin, I wanted to ask you, of course, you point out the need for increased funding, but I would also like you to touch on the review, how you would like to see proposals reviewed for these impact studies. And Dr. Winner, I am going to give you a chance——

Dr. COLVIN. Right.

Mr. BELL [continuing]. To touch on that as well.

Dr. COLVIN. That is a real concern. I think that when you say societal impact, there is a—generally, that is going to mean social scientists. That is the code word, so the modification of that to include other topics will be important. As I say, I see two pieces to any societal impact research proposal. One is technology forecasting. What are you going to assume? Are you going to assume that there is going to be smart clothing that can merge with your body, detect its temperature, and maybe whisper in your ear people's names when they—you see somebody and you can't remember their name? It is possible that that could happen. Wouldn't that be great? Are you going to basically red team that?

Mr. BELL. That would be a big seller here.

Dr. COLVIN. Yeah, I figured. Are you going to red team that? Are you going to red team self-replicating swarms of, you know, potentially bioterrorists or other kinds of weapons that have the ability to sense and interact with their environment. I think that if you look at those two scenarios, they are both really interesting. Which one is actually going to happen? And the people best suited to evaluate that part of the proposal will be nanotechnology researchers, people very entrenched in the field who know what the capabilities currently are and know where the various disparate areas are going. So every proposal should have a review, which is consistent of a nanotechnology group.

However, there are the societal and ethical consequences, and hopefully environmental. And those should be reviewed by subject experts there. By relying only on one or the other, I believe that you will really weaken societal impact research overall. So you really need both components, especially the technology forecasting component is an essential recognition that that is a very important thing that only, I believe, nanotechnologists are able to peer review successfully.

Mr. BELL. One thing that concerns me when we have these——

Dr. COLVIN. Um-hum.

Mr. BELL [continuing]. Debates about societal and ethical concerns in regard to science is that sometimes they seem to be based more on misinformation than real information. I want to give you a chance to comment on some of Dr. Winner's statements——

Dr. COLVIN. Um-hum.

Mr. BELL [continuing]. Earlier as far as a post-species and those types of things that obviously when put out there are going to scare a lot of people. Is that, as far as you understand it, the goal of people involved in nanotech research?

Dr. COLVIN. You know, I don't have a crystal ball. I wish I did to know where we were going to be in 30 years. And the further out you try to go, the more difficult it will be to get accurate predictions about technology. I believe—you know, my personal opinion, especially as a chemist, is that many of the self-replicating concepts and the ways that people propose to build them are untenable, so I believe we are not going to see that. And I believe that those concerns, especially about human intelligence taking over the world, I would certainly side with Mr. Kurzweil on that. I believe it will be incorporated into part of who we are. But those are very, very far out things that are so far in the distant future, it is difficult to study them with any great level of accuracy, because it could be many different possibilities.

The near-term effects, which really are going to affect the trajectory of what—where those futures might be, are going to be, perhaps, more mundane, but just as important to developing a culture and a public awareness and acceptance of this area. So for that reason, I really believe it is important that we look very closely at, particularly, health impact, because that is the one we see now, but to do that in preparation for what might happen in the future. But technology forecasting is a dangerous game, so I kind of feel uncomfortable, as a scientist, going there, but I do think that you can go too far out, and that has the disadvantage of being very unlikely, perhaps, technologically, and also, of course, public education and interaction issues become——

Mr. SMITH OF MICHIGAN. The gentleman's time has expired, but we will do a second round, if——

Mr. BELL. Can I ask one more question, Mr. Chairman——

Mr. SMITH OF MICHIGAN. Certainly.

Mr. BELL [continuing]. Of Dr. Winner, because you talked about focusing on what the research could mean or what they will mean, and don't you think the focus should be on what it could mean, because it—she brings up—Dr. Colvin brings up the health impact. Energy is another area where a lot of research is going forward, two areas of huge concern throughout the Nation. And if we are able to make advances on those, I think most people here would be behind that. So when you say "will mean", do you mean "could mean" or what do you mean by that?

Dr. WINNER. Well, I do mean "could". As I listen to this conversation, one thing that strikes me is that in evaluating these ethical and societal consequences, outcomes, that I think one serious mistake would be to adopt one single strategy, let us say, to hire the social scientists and the philosophers and get them studying. I think we need, probably, at least two or three different strategies here that would, perhaps, involve different kinds of people in long-term assessments.

I regret to say that one thing that I have seen happen more than once is that you have a very cozy relationship between the researchers and the people who are supposedly doing the ethical evaluations. The people doing the, let us say, bioethics, don't want to offend the people that they are working with. So what happens is you get only the most trivial kinds of issues, typically, raised. And in this field of research we are entering into, they are the most momentous issues that are—that society is going to need to address, and we need to find strategies that will bring those into the open for good, critical evaluation.

Mr. SMITH OF MICHIGAN. The gentleman from Oregon, Mr. Wu.

Mr. WU. Thank you. Well, for my friends from California, one of whom is still here, Mr. Sherman may think that the last time human recognition of superior intelligence was when Neanderthal ran into Cro-Magnon 100,000 years ago. But when I ran into Mr.

Sherman on Pennsylvania Avenue last week, I immediately recognized him of superior intelligence.

With respect to the comments made by the other gentleman from California, Mr. Rohrabacher, with whom I share many concerns, I think there are quagmires in their quagmires. And sometimes, you just charge through a quagmire. Sometimes you go around a quagmire. Sometimes you build a bridge over a quagmire. Sometimes you fly over a quagmire. And sometimes, a quagmire doesn't exist. If you spend too much time worrying about the quagmire at the edge of it, you do have some legitimate concerns of the type that Mr. Rohrabacher expressed. However I think it is important to, as best we can, look at some of these quagmires in advance so that sometimes we don't go charging into one and find that it is a little bit over our heads or that, you know, we might have some problems with it that we might not otherwise have anticipated.

Having said that, I want to return to just one very simple question for Mr. Kurzweil, because I was in the back of the room when I heard you first describe the further out challenge, and I am glad to see that you have a background in software. That is where I come from, too, except I did software legal work, and I could never understand how software really ran on a chip or how it interacted with a substrate and so on. And the thing that I am having a little—you know, I heard you mention this, and—how would nanotechnology become self-replicating? Just how would that work? And what makes it any easier for a nanotech machine to self-replicate when it seems pretty difficult to have a self-replicating full-sized machine? What—can you go into this a little bit for me?

Mr. KURZWEIL. Well, we have an example of a self-replicating machine, which are biological systems and biological cells. These are, in fact, nanoscale——

Mr. WU. Oh, yes, but that is not the question asked, because the problem with biological examples is we have not thus far successfully replicated them except—unless you want to call farming.

Mr. KURZWEIL. Well, we are actually pretty close to creating completely synthetic organisms. But I think the goal is not to have self-replication of non-biological entities happen naturally. But if you are going to start with building devices at the atomic level, and you want to actually create a product that, say, can interact with humans, it has to have some scale. Somewhere in the manufacturing process, there has got to be a scaling up process. We have that in the human body. We have ribosomes that are little machines that actually assemble protein machines. So there is a form of self-replication going on with one device building another and doing that in parallel. We will have to have some comparable examples to that, if we are going to actually engineer things at the atomic level, because there are many trillions of molecules in a device that we can actually interact with. And how to do that safely so that the self-replication doesn't go awry, which is really the course—source of all problems we have with disease, for example, is a key——

Mr. WU. The reason why I am asking this question is that if we are on the verge of self-replicating machines, then that is something that we want to put a red team on and something we want to pay a lot of attention to. It is my impression, and correct me if I am wrong, but we understand some things about ribosomes, but there are certain proteins that are not that complicated where we don't understand how they fold into a form that works. And so I am trying to get a sense from you about whether the self-replicating machinery that I don't think we have seen in full scale. I mean——

Mr. KURZWEIL. Well, you are correct. We don't——

Mr. WU [continuing]. Since we haven't seen that, are we really on the edge of nanotechnology that is self-replicating?

Mr. KURZWEIL. We are not on the verge of—I think we have commented that that is a number of generations away. We haven't solved the protein-folding problem yet. A new generation of supercomputers that are emerging, it is expected we will get to be able to actually simulate protein folding for the first time. But we get from here to some of these very futuristic scenarios that Dr. Colvin alluded to being difficult to anticipate not in one step, but through a series of generations of technology where each one is more conservative. Right now, we are developing nanoparticles and we are—and Department of Defense is developing smart dust, which are insect-sized devices. And we are shrinking technology. So through five, six, ten different generations of technology, we will get from here to devices that can scale up the way we see in the biological world.

But it is important to note that these generations are getting faster and faster. It used to be a generation of technology was equal to a human generation. Now it is maybe two, three, four years. And 10 years from now, it is going to be one or two years. So it won't be that long before we get through five or six generations. So I think scientists have to begin to overcome their reluctance to look more than one or two generations ahead, because the generations are so short.

Mr. SMITH OF MICHIGAN. The gentleman's time has expired——

Mr. WU. Thank you, Mr. Kurzweil.

Mr. SMITH OF MICHIGAN [continuing]. But Mr. Wu, we will do a second round, if you wish.

Mr. WU. I will just join Mr. Sherman at lunch.

Mr. SMITH OF MICHIGAN. Ms. Peterson, you wanted to give a quick reaction to Mr. Wu's question.

Ms. PETERSON. Yes, it is a great question. And I think it is an important one to deal with. It turns out we don't need to solve the protein folding problem before we make these nanoscale machines, and here is why. Proteins are—have been evolved over a long time to do what they do, but they haven't been evolved for predictability. There is no connection there at all. In fact, they are—they tend to be just on the edge of stability. When we design our own machines at the nanoscale, we can design specifically for predictability and buildability. So it is a—it is conceivably—in some ways, it is actually a simpler problem.

Mr. WU. I just want to add one comment to that. I didn't mean to imply that protein—that we need to solve the protein issue. It is just that Mr. Kurzweil seemed to imply that we were understanding this biology pretty well. My question really went to if you can't build a big self-replicating machine, what makes you think you can build a small self-replicating machine and how would that really work? That is the important question.

Mr. SMITH OF MICHIGAN. Very briefly, Ms. Peterson.

Ms. PETERSON. Just—I will try to do it in one sentence. One thing that helps a lot at the nanoscale is that you are working with molecules that are actually atomically perfect. At a small enough scale, atoms are either in the right place or the wrong place. When you build a big machine, things aren't that perfect. Things aren't atomically perfect, the pieces that you are working with. So there are some ways that it is—and it is a very challenging problem, don't get me wrong. But there are some ways that it is easier, actually.

Mr. SMITH OF MICHIGAN. With semicolons, that was a good one sentence. I think, Ms. Peterson, then maybe you and Mr. Kurzweil, what right now currently is existing now and what do you see is the potential for private sector investment and interest in nanotechnology? First you, Ms. Peterson.

Ms. PETERSON. There is tremendous private sector interest and involvement in near-term nanotechnology. I don't have the exact numbers, but there is plenty of money out there for products that can get to market in the next, say, three to five years and have a substantial sale. So it is absolutely huge, and not just in the United States, certainly in Europe and Japan and around the world. So—however, in the longer-term, if it is not fundable today by venture capital, people, at least out in Silicon Valley, say, "Go get a grant." So the expectation is that government does all of the funding right up until it is time to go to market, pretty much. That is the current feeling out there.

Mr. SMITH OF MICHIGAN. And your comments, Dr. Kurzweil.

Mr. KURZWEIL. There is a mini boom right now in venture capital for nanotechnology, but actually, aside from nanoparticles, which isn't really consistent with the original conception of molecular engineering but is nanoscale, most of the activity isn't really quite nanotechnology, it is something called MEMS, Microelectronic Mechanical Systems. But these are devices a little bit bigger than nanotechnology, but as I mentioned, as a pervasive trend toward miniaturization.

But the prospect for these MEMS scale devices is very exciting. We have mentioned the medical applications. I will mention another, which is energy. The Administration has a goal of the hydrogen economy, and one of the best ways to do that is to actually use MEMS, tiny little devices that are essentially microscopic fuel cells, and then you can power things inside the body or scale them up. I know one company, innovative fuel cell technology that is actually building MEMS based fuel cells that can power portable electronics for weeks rather than hours. And it is inherently safe, because you build up thousands or hundreds of thousands or millions of little cells, each of which have protection built into them. So it has a number of safety features comparable to biological systems.

Mr. SMITH OF MICHIGAN. Dr. Colvin, are you and Dr. Smalley seeing that kind of interest and participation at Rice?

Dr. COLVIN. You mean from the——

Mr. SMITH OF MICHIGAN. Private sector.

Dr. COLVIN [continuing]. Industry? Oh, yeah. I think that there is—it is clear in, I would call, nano-manufacturing from the bottom up, which is specialty chemical industries or pharmaceutical industries or it can be coming more interested in producing nanoparticles. I would say that those are not just a little, you know, mundane element. They will be core elements to more complex structures, but there is a great deal of interest, both in established corporations, surprisingly enough, as well as venture capital. So we will see.

Mr. SMITH OF MICHIGAN. Well, my question—let me ask a question on safeguards. I mean, with biotechnology, we probably have the best—by far, the best safeguards in the regulatory process in biotechnology with the FDA, with USDA, and with EPA all interacting to try to assure that anything that we develop in the arena of biotechnology outside of pharmaceuticals is going to have a very strict review. Any thoughts or suggestions on the similar kind of structure in terms of review and oversight with nanotechnology? Whoever wants to answer.

Mr. KURZWEIL. I would put in—it is not in direct answer to your question, but I do have a concern about the regulatory process we have in biotechnology, which I alluded to earlier. When it comes to intentional abuse of these technologies, irresponsible practitioners, bio—would-be bioterrorists, don't have to follow those regulations. And we are not putting enough resources as a society, enough money into developing the defense of technologies. And we—I used, really, the software virus as an analogy. We have kept one step ahead of the destructive applications. If we want to be as successful in biotech and ultimately nanotech, we are going to have to put explicit resources. We are very close, actually, to anti-viral drugs. We are not going to be able to invent an antidote for each new bio-peril that comes along. We are going to have to have some general broad tools, which we don't have today. We are not investing enough into it, and we have to figure out some ways to streamline the regulatory process. We can't take eight years to get FDA approval on a protection from bioengineered pathogens.

Mr. SMITH OF MICHIGAN. Any other comments?

Dr. COLVIN. Yeah, I will comment. I think that the regulation question is a really important one. It is, perhaps, beyond the privy of the NNI legislation, but——

Mr. SMITH OF MICHIGAN. Mr. Sherman——

Dr. COLVIN [continuing]. EPA and—as well as NIEHS, the National Institute for Environmental Health Sciences, are both organizations that would be in the line for thinking about potential, with respect to materials, regulation issues. But it is very clear we need to study these materials first and regulate second. And the studies haven't happened, so——

Mr. SMITH OF MICHIGAN. Thank you. Dr. Winner.

Dr. WINNER. Well, my only comment here would be how did all of these priorities reach such a level on the national agenda? You know, I hear from schoolteachers the schools are falling apart, their budgets are being cut. There is a crisis in all state governments with funding basic social needs. You know, the—our society has tremendous problems, tremendous issues that it faces. And yet we are looking at hundreds of millions, perhaps multiple billions of dollars to, as Ms. Peterson points out, not only investigate a new area of scientific research, but in effect, heavily subsidize one new industrial enterprise after another. My question would be, you know, well who decided that? Maybe the answer is the Executive Branch and the Congress. But I see this as a real challenge to priority setting in the United States right now. I wonder if this money, a lot of this money, is going to be badly wasted in a time of great need.

Mr. SMITH OF MICHIGAN. Ms. Peterson.

Ms. PETERSON. For near-term nanotechnology regulation, I think Dr. Colvin would probably be the better expert. For longer-term nanotechnology, the two main areas would be:

Accidents: We already have a set of draft rules. I think over time, just as with the early days of biotech—in fact, these rules were inspired by those—there was a gradual process where voluntary drafts slowly turn into, eventually, requirements. And I think we will see that here. There is also—

Regarding abuse, there is going to be very serious arms control issues, but they are not that different, really, from chemical and biological warfare issues, which means they are very difficult.

Mr. SMITH OF MICHIGAN. Mr. Sherman.

Mr. SHERMAN. Thank you. I thank the gentleman from Oregon for his comments. I have been sitting here trying to think of a pithy rejoinder, and I can't think of one, thus illustrating the falseness of his generous comments.

Mr. WU. Just remember the beta tapes went. You know, the better technology doesn't always win out.

Mr. SHERMAN. His comments are about self-replication. I guess there is kind of—we are thinking—or at least I am envisioning two types of self-replicating technology. One is the obvious, but it won't be here for, I think one of you said 26 years. And that is in every science fiction book, the smart robot always builds himself, and it is always a himself, a companion. So we can have the self-replication in the self-aware sense, but that is at least a generation away. And then there is this idea of the self-replicating molecule, which is DNA and life. And I was interested in Ms. Peterson's comments, but I didn't fully understand them. Are you talking about, in effect, synthetic life that is based on a more logical DNA molecule or——

Ms. PETERSON. No.

Mr. SHERMAN. Well, what were you talking about in the sense of a self-replicating molecule that was not—did not have to solve the protein-folding problem?

Ms. PETERSON. Oh, okay. I don't think I used the term "self-replicating molecule". Although, and Dr. Colvin, as a chemist here, could address this, I believe there are such things, actually, as molecules that will template off themselves.

Dr. COLVIN. Oh, yeah. It is not uncommon.

Mr. SHERMAN. Is there scientific work being done to create new self-replicating molecules, other than those based on the DNA?

Dr. COLVIN. So the question is is there scientific work being done? It is a difficult question to answer, because there are clearly molecules that have the ability to template themselves, if put in the right environment. Is that self-replication? Does the molecule think? No. It obeys the laws of thermodynamics. So it is very common in chemistry to have that, and it is not—it is just a property of some particular systems. So I don't see that as self-replicating in the terminology that people are using it.

Mr. KURZWEIL. I think that your concern is something in between a small, self-replicating molecule or a large, self-replicating robot. But we are talking about our small machines that are bigger than a molecule, but have some scaling properties, some ability to be scaled up to millions or trillions of devices. One way of doing that would be self-replication. But I think the industry has realized that that would be dangerous, so we really want to have controlled replication and to avoid runaway self-replication. But there has to be some way to scale up, because if you have two or three little devices that are microscopic in size, it doesn't do you any good. We need billions or trillions of them. So there has to be some form of replication in the process. And how to do that in a controlled fashion is the key safety issue in the long-term.

Mr. SHERMAN. I don't know if Dr. Colvin——

Dr. COLVIN. Well, I think why—it comes down to what you mean by "self-replication". Molecules that are able to template themselves are interesting, but they don't have—I think people tend to answer—when we think about this, we think of little tiny people that are really nano that go around and do stuff. And that is where it breaks down, because you need a power source. You have got to have multiple functions.

So when you think of the complex systems that people are proposing for the nanoscale, that is when you can say there are just not enough pieces to fit together on that size. Because there is a big difference between the MEMS devices that Mr. Kurzweil is talking about, which if they filled this room, the nanostructures that we think about would be the size of a baseball or probably tinier. And there is a big difference between even the micron length scales and the nano with respect to the scaling and physical and chemical properties. So I don't take it as a given that things are simply going to march smaller and smaller. I believe there will be fundamental alterations to how we have to conceive of creating systems on those length scales. And that is what I—why I feel extrapolations are a little bit dangerous.

Mr. SHERMAN. Dr. Winner and Mr. Kurzweil have addressed from opposite standpoints that interesting question what is a human being. And I—Dr. Kurzweil puts forward the idea that wherever evolution takes us, if it produces a self-aware and ambitious, exploring entity, that that is human. And Dr. Winner takes the more—well, he wants, I guess, to count the fingers and count the toes. And I don't know if there is a way to address this in the remaining 15 seconds, but——

Dr. WINNER. Well, one important question is who gets to do the counting at all. At last, the last statistics, I understand, there are about six billion-plus humans on the planet, most of whom, the overwhelming majority of whom, are not involved in these projects. They might be interested to find out these plans are in the works, and they might even want to have a say.

Mr. SHERMAN. I think they would. And it does go back to the question as to if Mr. Kurzweil was a Neanderthal and met that Cro-Magnon whether he would be happy or unhappy. And I will let him respond, if he wants to.

Mr. SMITH OF MICHIGAN. Very briefly.

Mr. KURZWEIL. I think rather than developing non-biological systems, although that will happen, I think our primary destiny is to enhance our own capabilities. I mean, I like having ten fingers and ten toes, but incrementally, one step at a time as we overcome various types of physical afflictions and limitations of our human capability, we will be enhancing our whole civilization. We have done that already. We are doing things today that couldn't be possible without the intimate merger with our technology. And we are going to stay on that path.

Mr. SMITH OF MICHIGAN. The Chair calls on Mr. Barton, another gentleman from Texas where nanotechnology is being explored at the University of Texas.

Mr. BARTON. Well, thank you. I am not going to ask any questions. I just came by to show support. There is a University of Texas Nanotechnology Center at the University of Texas at Arlington that I have just been through and helped to get several grants in the last several years. It is an amazing technology, and we are still a ways from commercialization, but obviously, it has got the potential to do great things in the future. I want to appreciate you, Chairman Smith, for holding this hearing and thank my—thank all of the witnesses, especially Dr. Colvin, who is from Texas, for being here.

Mr. SMITH OF MICHIGAN. Mr. Wu, you had a question.

Mr. WU. Thank you very much, Mr. Chairman. As you know, I usually ask short, quick questions, but I think I will exercise the user prerogative of members of this panel. And I just want to comment on a range of things that I have heard today. And by the way, Dr. Colvin, Dr. Winner, I appreciate your last comments. They were very, very helpful.

You know, there is a full spectrum of policy and regulatory and legal responses to new technologies. And we have historic examples of what they can be. In many respects, the Nuclear Test Ban Treaty is nothing but a ban on experimentation, and it is a ban that many nations have agreed to. Some of us believe that the Nuclear Test Ban Treaty has done good things.

At the other end of the spectrum, you look historically and what the church tried to do with Galileo and did with many others, I think we would look back and say historically that was not such a good thing. Those are sort of endpoints in the spectrum, but somewhere in between are issues that we have to deal with on an everyday basis. And I would just like to suggest to my colleagues on this panel, some of whom are here, and many of whom are not right now, that it is not such a simple thing to decide we are just going to let the scientists and the engineers go do their work, because if we just think about some of the issues that we, as a Congress, have been dealing with recently, stem cell research. I join some of my colleagues on it—on that issue and differ with some of my colleagues on that issue in terms of where we should be going with stem cell research. And interestingly enough, if you flip to something not that far apart from it, but I think distinct from stem cell research, I share a position with a different set of friends and colleagues on human cloning. And again, it is a very appropriate, I think, set of lines that we should be drawing in some public way, not necessarily here in Congress. But just because people are scientists or engineers doesn't necessarily give them a stronger vote in the societal decision about whether we should be exploring the solar system, as Galileo was doing, or doing self-replicating nuclear reactions the way that some scientists would be doing or in some of these other, you know, middle ground issues, such as stem cell research or human cloning. It is a difficult line-drawing exercise every single time. And that is our business. We are here to draw lines and hopefully wise ones with you all's assistance. And I would just like to add that the regulatory response can be a positive one, it can be a negative one. It is not always eight years that, you know, something is in the pipeline. Some of the anti-cancer drugs, which were found to be very, very effective, popped out of the pipeline in a matter of days, weeks, or months, at the most, and did not take eight years. So hopefully, we can engage in an important line-drawing process and end up, if we need to, with a regulatory process, which is appropriate to the technology, and not automatically regulate or automatically reject regulation because of the different technologies at hand.

Thank you, Mr. Chairman. I appreciate your——

Mr. SMITH OF MICHIGAN. Thank you. With your permission, what we will do to conclude this hearing is ask each witness for maybe your—any comments that you would like to make guiding this committee as we start looking at our markup on April 30 for the nano bill, H.R. 766. So if you would have any comments and could sort of hold it down to about a minute to guide our Committee as we look at markup.

Mr. KURZWEIL. Well, quickly, just to respond to Representative Wu, I think your comments are well taken. I have advocated fine-grained relinquishment in response to the call by Bill Joy and others for broad relinquishment. Why don't we just do away with nanotechnology? There are specific narrow tasks we would rather not see funded. I mean, how to modify common flu and cold pathogens to be destructive, that is not something we would want to fund. We don't want to see on the Internet the genomes of the ten top pathogens. So there are things that we—that are particularly dangerous that we need to deal with through regulation.

And I would advocate that we—as we did with the Genome Project, put three to five percent of the budget and devote it to the ethical, legal, social implications, so called ELSI of these technologies. And I do think it has to be a balance between scientific analysis by scientists as well as an understanding of the ethical and cultural issues by people who are expert at those domains.

Mr. SMITH OF MICHIGAN. Dr. Colvin.

Dr. COLVIN. Yeah. Just to sort of summarize my viewpoint. First of all, in societal impact, hopefully environmental impact will be part and parcel of that. It should be. And the three things that I kind of think of when I look at this legislation are the words. Strong support for this type of work. I think I outlined what some of the natural barriers are, just human nature. Most scientists would rather cure cancer than do work that finds out some nanomaterial might cause cancer, so you need to be very vigilant if you want this work to continue and support it strongly. The methods in which it occurs, we have heard that we need to have collaborative enterprises. And finally, the resources are the most important—an allocation for this type of research, I believe, is very well recommended.

Mr. SMITH OF MICHIGAN. Thank you. Dr. Winner.

Dr. WINNER. Yes. Two things. On my suggestion about the possibility of citizens panels, the relevant part of the NSF is called social dimensions of engineering, science, and technology. That work also goes under the label of consensus conferences, if the Committee wants to look into that. That would be one—my one suggestion about how the bill might be changed.

The other thing I would like to do is to express my gratitude to the Committee and its staff for assembling so diverse a group of panelists today to interact and to exchange views. I think this is actually quite unusual right now in American society where you can have issues of this kind so intelligently questioned and expect to have a diversity of responses coming back at you, who are, after all, the decision makers.

Thank you.

Mr. SMITH OF MICHIGAN. Thank you. Ms. Peterson.

Ms. PETERSON. Just to reiterate, we could use public outreach and discussion perhaps even more than social science work in this area. And you have seen there is some controversy here, and that is a good thing, as Dr. Winner points out. The hopes and the fears about this longer-term work, molecular manufacturing, the self-replication issue, are spilling over onto the near-term work. This is a problem for the folks doing the near-term work. I would say we should just go ahead and do that feasibility study, get this cleared up, and then we can move on to be doing effective social implications work and also public outreach.

Mr. SMITH OF MICHIGAN. Thank you very much. With the permission of the witnesses, some questions that staff would have liked to ask but weren't by the Members, if you would consider responding to any questions that might be sent to you. Again, thank you all very much for giving us your wisdom and knowledge. And with that, the Committee is adjourned.

[Whereupon, at 12:20 p.m., the Subcommittee was adjourned.]

Appendix 1:

Additional Material for the Record

108TH CONGRESS
1ST SESSION

H. R. 766

To provide for a National Nanotechnology Research and Development Program, and for other purposes.

IN THE HOUSE OF REPRESENTATIVES

FEBRUARY 13, 2003

Mr. BOEHLERT (for himself, Mr. HONDA, Mr. EHLERS, Mr. HALL, Mr. SMITH of Michigan, Mr. GORDON, Mrs. BIGGERT, Ms. EDDIE BERNICE JOHNSON of Texas, Mr. BARTLETT of Maryland, Ms. LOFGREN, Mr. GUTKNECHT, and Mr. BISHOP of New York) introduced the following bill; which was referred to the Committee on Science

A BILL

To provide for a National Nanotechnology Research and Development Program, and for other purposes.

Be it enacted by the Senate and House of Representatives of the United States of America in Congress assembled,

SECTION 1. SHORT TITLE.

This Act may be cited as the "Nanotechnology Research and Development Act of 2003".

SEC. 2. DEFINITIONS.

In this Act———

(1) the term "advanced technology user facility" means a nanotechnology research and development facility supported, in whole or in part, by Federal funds that is open to all United States researchers on a competitive, merit-reviewed basis;

(2) the term "Advisory Committee" means the advisory committee established under section 5;

(3) the term "Director" means the Director of the Office of Science and Technology Policy;

(4) the term "Interagency Committee" means the interagency committee established under section 3(c);

(5) the term "nanotechnology" means science and engineering aimed at creating materials, devices, and systems at the atomic and molecular level;

(6) the term "Program" means the National Nanotechnology Research and Development Program described in section 3; and

(7) the term "program component area" means a major subject area established under section 3(c)(2) under which is grouped related individual projects and activities carried out under the Program.

SEC. 3. NATIONAL NANOTECHNOLOGY RESEARCH AND DEVELOPMENT PROGRAM.

(a) IN GENERAL.—The President shall implement a National Nanotechnology Research and Development Program to promote Federal nanotechnology research, development, demonstration, education, technology transfer, and commercial application activities as necessary to ensure continued United States leadership in nanotechnology research and development and to ensure effective coordination of nanotechnology research and development across Federal agencies and across scientific and engineering disciplines.

(b) PROGRAM ACTIVITIES.—The activities of the Program shall be designed to———

(1) provide sustained support for nanotechnology research and development through———

(A) grants to individual investigators and interdisciplinary teams of investigators; and

(B) establishment of interdisciplinary research centers and advanced technology user facilities;

(2) ensure that solicitation and evaluation of proposals under the Program encourage interdisciplinary research;

(3) expand education and training of undergraduate and graduate students in interdisciplinary nanotechnology science and engineering;

(4) accelerate the commercial application of nanotechnology innovations in the private sector; and

(5) ensure that societal and ethical concerns will be addressed as the technology is developed by———

(A) establishing a research program to identify societal and ethical concerns related to nanotechnology, and ensuring that the results of such research are widely disseminated; and

(B) integrating, insofar as possible, research on societal and ethical concerns with nanotechnology research and development.

(c) INTERAGENCY COMMITTEE.—The President shall establish or designate an interagency committee on nanotechnology research and development, chaired by the Director, which shall include representatives from the National Science Foundation, the Department of Energy, the National Aeronautics and Space Administration, the National Institute of Standards and Technology, the Environmental Protection Agency, and any other agency that the President may designate. The Interagency Committee, which shall also include a representative from the Office of Management and Budget, shall oversee the planning, management, and coordination of the Program. The Interagency Committee shall———

(1) establish goals and priorities for the Program;

(2) establish program component areas, with specific priorities and technical goals, that reflect the goals and priorities established for the Program;

(3) develop, within 6 months after the date of enactment of this Act, and update annually, a strategic plan to meet the goals and priorities established under paragraph (1) and to guide the activities of the program component areas established under paragraph (2);

(4) consult with academic, State, industry, and other appropriate groups conducting research on and using nanotechnology, and the Advisory Committee; and

(5) propose a coordinated interagency budget for the Program that will ensure the maintenance of a balanced nanotechnology research portfolio and ensure that each agency and each program component area is allocated the level of funding required to meet the goals and priorities established for the Program.

SEC. 4. ANNUAL REPORT.

The Director shall prepare an annual report, to be submitted to the Committee on Science of the House of Representatives and the Committee on Commerce, Science, and Transportation of the Senate at the time of the President's budget request to Congress, that includes———

(1) the Program budget, for the current fiscal year, for each agency that participates in the Program and for each program component area;

(2) the proposed Program budget, for the next fiscal year, for each agency that participates in the Program and for each program component area;

(3) an analysis of the progress made toward achieving the goals and priorities established for the Program; and

(4) an analysis of the extent to which the Program has incorporated the recommendations of the Advisory Committee.

SEC. 5. ADVISORY COMMITTEE.

(a) IN GENERAL.—The President shall establish an advisory committee on nanotechnology consisting of non-Federal members, including representatives of research and academic institutions and industry, who are qualified to provide advice and information on nanotechnology research, development, demonstration, education, technology transfer, commercial application, and societal and ethical concerns. The recommendations of the Advisory Committee shall be considered by Federal agencies in implementing the Program.

(b) ASSESSMENT.—The Advisory Committee shall assess———

(1) trends and developments in nanotechnology science and engineering;

(2) progress made in implementing the Program;

(3) the need to revise the Program;

(4) the balance among the components of the Program, including funding levels for the program component areas;

(5) whether the program component areas, priorities, and technical goals developed by the Interagency Committee are helping to maintain United States leadership in nanotechnology;

(6) the management, coordination, implementation, and activities of the Program; and

(7) whether societal and ethical concerns are adequately addressed by the Program.

(c) REPORTS.—The Advisory Committee shall report not less frequently than once every 2 fiscal years to the President and to the Committee on Science of the House of Representatives and the Committee on Commerce, Science, and Transportation of the Senate on its findings of the assessment carried out under subsection (b), its recommendations for ways to improve the Program, and the concerns assessed under subsection (b)(7). The first report shall be due within 1 year after the date of enactment of this Act.

(d) FEDERAL ADVISORY COMMITTEE ACT APPLICATION.—Section 14 of the Federal Advisory Committee Act shall not apply to the Advisory Committee.

SEC. 6. NATIONAL NANOTECHNOLOGY COORDINATION OFFICE.

The President shall establish a National Nanotechnology Coordination Office, with full-time staff, which shall———

(1) provide technical and administrative support to the Interagency Committee and the Advisory Committee;

(2) serve as a point of contact on Federal nanotechnology activities for government organizations, academia, industry, professional societies, and others to exchange technical and programmatic information; and

(3) conduct public outreach, including dissemination of findings and recommendations of the Interagency Committee and the Advisory Committee, as appropriate.

SEC. 7. AUTHORIZATION OF APPROPRIATIONS.

(a) NATIONAL SCIENCE FOUNDATION.—There are authorized to be appropriated to the National Science Foundation for carrying out this Act———

(1) $350,000,000 for fiscal year 2004;

(2) $385,000,000 for fiscal year 2005; and

(3) $424,000,000 for fiscal year 2006.

(b) DEPARTMENT OF ENERGY.—There are authorized to be appropriated to the Secretary of Energy for carrying out this Act———

(1) $197,000,000 for fiscal year 2004;

(2) $217,000,000 for fiscal year 2005; and

(3) $239,000,000 for fiscal year 2006.

(c) NATIONAL AERONAUTICS AND SPACE ADMINISTRATION.—There are authorized to be appropriated to the National Aeronautics and Space Administration for carrying out this Act———

(1) $31,000,000 for fiscal year 2004;

(2) $34,000,000 for fiscal year 2005; and

(3) $37,000,000 for fiscal year 2006.

(d) NATIONAL INSTITUTE OF STANDARDS AND TECHNOLOGY.—There are authorized to be appropriated to the National Institute of Standards and Technology for carrying out this Act———

(1) $62,000,000 for fiscal year 2004;

(2) $68,000,000 for fiscal year 2005; and

(3) $75,000,000 for fiscal year 2006.

(e) ENVIRONMENTAL PROTECTION AGENCY.—There are authorized to be appropriated to the Environmental Protection Agency for carrying out this Act———

(1) $5,000,000 for fiscal year 2004;

(2) $5,500,000 for fiscal year 2005; and

(3) $6,000,000 for fiscal year 2006.

SEC. 8. EXTERNAL REVIEW OF THE NATIONAL NANOTECHNOLOGY RESEARCH AND DEVELOPMENT PROGRAM.

Not later than 6 months after the date of enactment of this Act, the Director shall enter into an agreement with the National Academy of Sciences to conduct periodic reviews of the Program. The reviews shall be conducted once every 3 years during the 10-year period following the enactment of this Act. The reviews shall include———

(1) an evaluation of the technical achievements of the Program;

(2) recommendations for changes in the Program;

(3) an evaluation of the relative position of the United States with respect to other nations in nanotechnology research and development;

(4) an evaluation of the Program's success in transferring technology to the private sector;

(5) an evaluation of whether the Program has been successful in fostering interdisciplinary research and development; and

(6) an evaluation of the extent to which the Program has adequately considered societal and ethical concerns.

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