S. HRG. 109–294

FUTURE OF SCIENCE

HEARING

BEFORE THE

COMMITTEE ON COMMERCE, SCIENCE, AND TRANSPORTATION UNITED STATES SENATE

ONE HUNDRED NINTH CONGRESS

FIRST SESSION

NOVEMBER 18, 2005

Printed for the use of the Committee on Commerce, Science, and Transportation

U.S. GOVERNMENT PRINTING OFFICE

25–880 PDF WASHINGTON : 2006

For sale by the Superintendent of Documents, U.S. Government Printing Office
Internet: bookstore.gpo.gov Phone: toll free (866) 512–1800; DC area (202) 512–1800
Fax: (202) 512–2250 Mail: Stop SSOP, Washington, DC 20402–0001

SENATE COMMITTEE ON COMMERCE, SCIENCE, AND TRANSPORTATION

ONE HUNDRED NINTH CONGRESS

FIRST SESSION

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FUTURE OF SCIENCE

FRIDAY, NOVEMBER 18, 2005

U.S. SENATE,
COMMITTEE ON COMMERCE, SCIENCE, AND TRANSPORTATION,
Washington, DC.

The Committee met, pursuant to notice, at 10:15 a.m. in room SD–562, Dirksen Senate Office Building, Hon. Ted Stevens, Chairman of the Committee, presiding.

OPENING STATEMENT OF HON. TED STEVENS, U.S. SENATOR FROM ALASKA

The CHAIRMAN. My apologies. It's a strange morning over there on the floor, and I'm hopeful that some of our colleagues will join us. For the information of our guests and witnesses, we've had a little confrontation on the conference report on the Patriot Act, and also on being able to get the continuing resolution passed, which must be passed today and get to the President today. And he happens to be overseas, so it's a very interesting problem. But let me thank you all for coming.

Through the years, we've been amazed by the results of our Nation's scientific research. And because of these advancements, the United States has been able to capture and maintain its leadership position in science and technology. Our history clearly demonstrates our reliance on science, and will undoubtedly serve as the basis for our future growth and success.

I'm really pleased to be able to discuss research, technology, innovation, and education as the pillars of our success for the 21st century with these distinguished gentlemen who are at the table. Dr. Peter Agre, vice chancellor of science and technology, professor of cell biology, professor of medicine, at Duke University. Dr. Agre received the 2003 Nobel Prize in Chemistry for his discoveries concerning channels in cell membranes. Dr. Eric Cornell, senior scientist, National Institute of Standards and Technology, Technology Administration, U.S. Department of Commerce. Dr. Cornell received the 2001 Nobel Prize in Physics for his research leading to the landmark 1995 creation of the Bose–Einstein condensate and early studies of its properties. Dr. James R. Heath, Elizabeth Gilloon professor of chemistry at the California Institute of Technology, was named by Scientific American as one of the top 50 visionaries for his research in fabricating and assembling, utilizing nanocomputers. Dr. Samuel C. Ting, Thomas Dudley Cabot professor of physics at MIT. Dr. Ting received, in 1976, the Nobel Prize in Physics for his discovery of the charmed quark, one of nature's basic building blocks.

I do thank you for coming. I regret that this is the day it's happened, when we have so much going on out there that is so controversial. And we were in late last night. We left the floor last night at midnight. So, I don't know how soon my colleagues will join us. I do know, however, that you are on national television, and you're not only speaking to us, but you're speaking to the country.

So, I appreciate your coming to testify today. I would hope that your comments will lead us to be actionary, rather than reactionary, in the fields that you represent. And I not only look forward to your testimony, but I look forward to Jim Heath joining me for fishing in Alaska again soon. And you're all invited sometime.

So, let me turn first to you, Dr. Agre.

STATEMENT OF PETER AGRE, M.D., VICE CHANCELLOR, SCIENCE AND TECHNOLOGY/PROFESSOR, CELL BIOLOGY AND MEDICINE, DUKE UNIVERSITY SCHOOL OF MEDICINE

Dr. AGRE. Good morning, Senator Stevens, staff members, guests. It's a pleasure to be here to discuss the future of science. And although I have notes, and these are distributed, I'd like to make my comments informal.

The CHAIRMAN. Whatever you all want to print in the record, we'll print. I'll be delighted to have you make the comments that you wish us to hear and understand, and the audience out there to understand, too, Doctor.

Dr. AGRE. Yes, sir. Thank you.

My laboratory was recognized for the discovery of how water is organized in biology. Water is often described as the solvent of life. Our bodies are about 70 percent water. This is shared by all life forms. Without water, there is no life.

The organized distribution of water is something that goes on all of the time. We never think about it. While we're sitting here, our brains are being coated with spinal fluid, our eyes are being filled with aqueous humor, water is being released into tears, sweat, saliva, and bile. Our kidneys are concentrating urine. The trees outside are taking up water from the ground. It may be surprising at this late state in science that the discovery of how water is moved in biological tissues is very recent. This emerged from a discovery made in our laboratory 14 years ago. And it deals with a family of proteins, which we've termed the aquaporins. These are the water channel proteins that cause water to enter cells and leave cells.

The discovery, itself, was sheer serendipity. We were pursuing another project. But it's now led to potential clinical advances. These aquaporins are involved in many important disease states. Aquaporin 0 defects cause cataracts. Aquaporins 1 and 2 are how our kidneys can concentrate urine. And I think anybody who had a Venti Starbucks coffee at the station this morning, by the end of this hearing, is going to feel a sensation of fullness in his bladder. That's Aquaporin 2 at work. Aquaporin 3 is important for the integrity of our skin. Beauty products are now being marketed, because of the induction of this protein. Aquaporin 4, in the brain, is very important. Oftentimes, individuals sustaining a stroke or a brain tumor die of the brain edema mediated by Aquaporin 4. Aquaporin 5 is important in the secretion of sweat, tears, saliva, protecting us from corneal abrasions, corneal injuries, dental caries, heat prostration. Aquaporin 7 and 9 are involved in the defense against starvation and also lead to obesity. Aquaporins in plants can be manipulated to increase drought tolerance. So, these are all discoveries that have flown from a very simple serendipitous observation in a small laboratory.

You've invited us to share our perspectives, and I thought an important perspective of how I got into science is my background. I'm a regular American citizen, grew up out in Minnesota. My mother and dad were the offspring of Norwegian farmers who settled in South Dakota. They did one thing very special with my five brothers and sisters and me. They read to us every night, from the Bible, from the great books, from popular scientific texts.

Also, my siblings and I all went to public schools out in Minnesota. And we were very, very fond of our teachers. They played important roles in the community. They were highly respected in the community. And they made what is otherwise boring textbook information quite interesting by bringing it to our lives. On the playground, during the 100-yard dash, we would then go back to the classroom to calculate our speed. We'd be taken on nature walks, taught optics, how we can create heat from light. Of course, as kids, we would sometimes misuse this information, using the magnifying glasses to incinerate ants or the little electrical circuits to shock each other. But, hey, we were kids, and that's science.

My own career pathway toward science was indirect. I did not choose to become a scientist because of scientific excitement, per se, but because I wanted to be a medical doctor. And as a medical student at Johns Hopkins, I was pursuing a research project in a basic science laboratory to uncover the basis of infectious diarrhea in the New World, the turistas. Not a very attractive disease topic, but one that's of great clinical significance. And while working in this lab, I had the opportunity of working alongside really exciting scientists who came from all over the world. We had Israelis, and a Palestinian. We had Chinese and a Filipino. We had an anti-Franco Spaniard and a debonair, cosmopolitan Italian. And everybody worked together and became the best of friends. We've maintained these collegialities ever since.

Now, that was in a U.S.-taxpayer-funded research laboratory. There was no drug development or private money involved whatsoever.

I would like to touch briefly on a few issues related to U.S. science.

First, I'd like to mention that I think the prominence which the U.S. science has had for a long time is not guaranteed in the future. My own laboratory has been free to collaborate with scientists within the U.S., but we have oftentimes gone outside of the U.S. in order to collaborate with the scientists with the best state-of-the-art technologies. We solved the localization of the aquaporin proteins in tissues working together with scientists in Norway and Denmark. We solved the atomic structure of the molecule, working together with scientists from Switzerland and Japan. And we did this because they were the best in the world.

Now, the U.S. Government's funding for science has been generous. It also comes with a fair degree of freedom. When an individual makes a discovery, he or she can then focus on that discovery, explore it further, even though it doesn't conform to the original plan. This is not possible in many pharmaceutical companies, where business plans dictate what individuals can do.

I fear that restrictions on the freedom to explore new and unexpected discoveries may dampen the quality of science in the United States.

I also fear that the funding for science, at this time of the huge budget deficit, is in jeopardy. And I'd just like to say that the reductions in funding may be cyclical, and we can look, maybe 36 months from now, that it will recover. When young scientists are coming through their training, they can't wait. Oftentimes, they have families to support. They need to get funded and get going. And the young scientists—young scientists, under age 40—are the sources of our best and freshest ideas.

I think this is particularly true for scientists trained in clinical medicine, who often will spend up to 10 years getting clinical training, in addition to the science. They're at a point in their careers where they must either get funded or they'll be forced into strictly clinical activities where they'll make no basic discoveries. And these are the discoveries that come quickly to the patient's bedside.

Another issue I'd like to just introduce is the dependence of the U.S. on non-U.S. scientists. Much of the outstanding research in the United States for the last decade has been done by scientists who have come here from overseas. These individuals don't just work in laboratories in low-brow positions. They oftentimes rise to the very top of American bioscience. Elias Zerhouni came here from Algeria. He's now the director of the National Institutes of Health. My boss, Victor Dzau, born in Shanghai, is now the chancellor for the Duke Health System. Chi Dang came from Vietnam, is vice chancellor for research at Johns Hopkins. Pedro Cuatrecasas, with whom I worked as a student, came here from Colombia, South America, became the vice president of Parke–Davis Pharmaceuticals.

The entry of non-U.S. scientists is now declining, and there are multiple reasons—visa restrictions and the like. There is also, I fear, a factor that is not widely recognized in the United States, and that's how the United States, on rare occasions, like other countries in the world, mistreats scientists. In the news, just recently, there was a re-analysis of the case of Wen Ho Lee, a Taiwanese-born computer scientist suspected of spying for the People's Republic of China, was held in solitary confinement for 1 year, shackled hand to foot, threatened repeatedly with execution if he did not confess. Independent review of the charges resulted in a dropping of the charges. This occurred during Janet Reno's tenure as Attorney General of the United States.

Most recently, Thomas Butler, a very well known infectious-disease expert, was arrested from his laboratory in Texas Tech University when plague bacillus samples disappeared from his lab. When the FBI investigated, suspecting bioterror, they found no evidence of this. But Butler was hounded and charged with 69 federal felony charges, eventually cleared of all serious issues related to bioterrorism, but convicted on some minor issues related to the budget use in Africa. He's now in prison in Texas.

The word of these individuals' fates, I think, is widely recognized. The colleagues of these individuals, outside of the U.S., I think are concerned with the atmosphere and the attitudes toward American scientists.

I'd like to touch just briefly on a couple of more issues.

The visibility of scientists in U.S. society is something I worry about. Our founding fathers included scientists. Benjamin Franklin, Thomas Jefferson, Benjamin Rush. Even during my childhood, we were able to see scientists on the network, on the wonderful Disney show. And I think probably some people here in the audience that are my age may remember these shows. Wernher von Braun talked to the children about rocketry. Nobel Laureate Glenn Seaborg discussed the chemical chain reaction with a demonstration so vibrant, anybody who saw that show will never forget it. He had a mousetrap with a pingpong ball. The trap goes off, the ball flies. Then he took us—took the cameras in a room where the floor was covered with mousetraps and pingpong balls. He threw a ball over his shoulder, suddenly two balls were in the air, four balls in the air, and, within seconds, the entire room was a cloud of pingpong balls and mousetraps flying.

The visibility, I think, is very important to raise the awareness of the American public toward the values of science. And some of the trends that we see now in the popular media are very concerning.

Four hundred years after the time of Galileo, 20 percent of Americans still believe that the sun revolves around the Earth. I'm told that half of Americans believe cavemen and dinosaurs coexisted, apparently because they saw it on the Flintstones. Our schoolchildren consistently are behind children from East Asia in science and math, and behind the schoolchildren from Eastern Europe. I think this has something to do with the general anti-intellectual climate in the United States and the failure of half of American citizenry to read a single book in a given year.

So, I'd like to close with just a few final words.

Louis Pasteur said that, "Chance favors the prepared mind." Having been raised in the post-Sputnik era myself, I feel fortunate to have benefited from a high-quality public-school education, and, subsequently, as a researcher funded entirely by the U.S. taxpayer. There are a few words that I'll read from the end of the Nobel banquet speech that I gave in Stockholm 2 years ago. And in this, I say, "Our single greatest defense against scientific ignorance is education. And early in the life of every scientist, the child's first interest was sparked by a teacher." Then I enjoined the audience to, "Join me in applauding the individuals that foster the scientific competence of our society and are the heroes behind past, present, and future Nobel Prizes, the men and women who teach science to children in our schools."

Thank you.

[The prepared statement of Dr. Agre follows:]

PREPARED STATEMENT OF PETER AGRE, M.D., VICE CHANCELLOR, SCIENCE AND TECHNOLOGY/PROFESSOR, CELL BIOLOGY AND MEDICINE, DUKE UNIVERSITY SCHOOL OF MEDICINE

Senator Stevens, Senator Inouye, and other Members of the Committee:

I. My Life in Science.

It is my pleasure to appear before you and speculate on the future of science. I admit to having no crystal ball, but I am here to give my predictive powers a workout. First, as requested, I will tell you about my own research.

A. Biological Water Channels—the Aquaporins.

Water is often described as the "solvent of life," since it has long been known to be the major component of the human body. About 70 percent of our body mass is water, and the same is true of all other life forms. Without water there is no life.

The organized distribution of water within and between body compartments is essential to our well-being. While you are listening to me speak, each of you is bathing the surface of your brains with spinal fluid, secreting tears to protect the surface of the orbits of your eyes that are filled with aqueous humor. You will be releasing water in your exhaled breath, sweat, saliva and digestive juices. Your kidneys will be concentrating urine. At the same time, the trees outside will be absorbing water from the soil and releasing it from their leaves. Despite major advances in molecular biology, the mechanism by which water enters and leaves cells was a long-unanswered problem in biology.

All of these processes involve a simple cellular plumbing system that is conserved throughout nature and is made from a family of proteins referred to as "Aquaporins." These proteins were a serendipitous discovery made in my laboratory 14 years ago while we were pursuing research of an entirely unrelated project. We now have greatly increased understanding of fundamental processes in physiology, and we anticipate that this knowledge will in the future allow us to prevent or treat a host of clinical problems.

B. Clinical and Physical Significance of Aquaporins.

AQP1 is responsible for a blood antigen incompatibility and water permeation through capillaries; defects in AQP0 result in cataracts; AQP2 is responsible for excessive renal concentration which underlies fluid retention in heart failure and pregnancy as well as defective concentration in bedwetting. AQP3 is known to enhance the integrity of our skin and is the focus of anti-aging skin products. AQP4 mediates the deleterious brain edema following strokes and head injuries and appears to prevent or ameliorate epileptic seizures. AQP5 is essential for normal function of our secretory glands protecting us from corneal injury, dental caries, and heat prostration. AQP7 is implicated in obesity and AQP9 is involved in the insulin-deficient and insulin-resistant forms of diabetes as well as the liver damage from arsenic poisoning. Plant aquaporins may be manipulated to increase crop tolerance to drought, and microbial aquaporins may be future targets of antibiotics. While our original discovery was initially a total surprise, we now look eagerly to accomplishing exciting new applications.

C. Future of Science as Predicted from my Experience.

In order to speculate about the future, I will need to revisit my own past. I have to tell you that I think my childhood was a wonderful preparation for a future in science.

1. Early Education.

Not to be underestimated is the importance of the human side of science. As my family and friends could tell you, I am a regular person from an unexceptional background. My parents were the offspring of Norwegian farming families from South Dakota. My mother never went to college, but my Father was able to study at the U of Minnesota and taught chemistry at St. Olaf and Augsburg Colleges—small liberal arts schools in Minnesota. Fortunately for my five siblings and me, our parents read to us every night from the Bible as well as the books of Laura Ingalls Wilder, Lewis Carroll, and Robert Louis Stevenson. I believe this provided the literary background helpful for any career.

My siblings and I attended public schools, and our teachers were highly respected members of the community. Growing up in the late 1950s and early 1960s, I certainly benefited from the post-sputnik emphasis on science in the classroom. Although children often find textbook math and science to be dull, our teachers brought the lessons to life: by doing practical calculations such as our speed in a 100 yard dash; by taking us on nature walks; by performing simple hands-on scientific demonstrations. We loved optics but sometimes used the magnifying glasses for unintended purposes, such as incinerating ants on the sidewalk, We were fascinated by building simple electrical circuits, even though we sometimes used them to shock each other. Our excuse was always "But hey, it's science!"

2. Career Pathway.

I actually did not intend to pursue a career in pure science but studied science because I wanted to become a physician. I was a medical student when I really became excited about science while working on a research project to identify the cause of infectious diarrhea—often referred to as the "la Turistas." In a lab at Johns Hopkins that was entirely funded by U.S. taxpayer support, I worked alongside an exciting and colorful international cohort of scientists—including Israelis and a Palestinian, Chinese and a Filipino, an anti-Francoist Spaniard and a debonair Italian. Despite the different cultures we became the best of friends and have remained colleagues ever since.

Determined to combine clinical care and medical research, I was fortunate to receive an early NIH grant for clinical investigators that allowed me to work in a lab to gain the experience needed to succeed at science. I do not wish to underplay the difficulty though, and my family always encouraged me, even though it meant forgoing a potentially lucrative medical practice, to pursue my dream. I was optimistic despite the financial compromise, the absence of a promised faculty position, and the total lack of certainty that I would ever succeed.

II. Issues Related to U.S. Science.

Due to the longstanding generosity of the American Taxpayer and the wisdom of both of our national political parties, the United States has been the world's leading scientific presence for as long as I can remember. Unfortunately, I am not completely optimistic about the future, and I greatly fear that we will be overtaken by other countries.

A. Prominence of U.S. Science.

My laboratory has always had complete freedom to collaborate with the best scientists in the U.S. Nevertheless, you may be surprised to learn that it was our collaborations with scientists in Europe and Japan that led us quickly in new directions that were not feasible here in the U.S. For example, our high resolution immuno-electron microscopy studies were undertaken in collaboration with investigators in Denmark and Norway. The atomic structure of the aquaporin protein was solved by membrane crystallographic studies with scientists in Switzerland and Japan. We collaborated overseas simply because these scientists were the best in the world in the highly specialized techniques.

B. U.S. Government Funding of Science.

My own career was entirely supported by research funds from the U.S. taxpayers in the form of NIH grants. In my own case, the research funding provided an opportunity to pursue science by following discoveries—even when they did not conform to the original plan. If I were a scientist in a traditional industrial laboratory, I would never have had the flexibility to discover and further explore the aquaporin water channels, because this project did not fit into the company's primary objectives. I worry that U.S. Government funding for scientific research may some day come with absolute restrictions that prevent change of focus when unexpected discoveries appear.

I also worry that U.S. Government funding for scientific research will be reduced at this time of a huge federal budget deficit. Unfortunately, failure to provide steady research funding will be most severely experienced by the newly trained scientists who are beginning their independent research programs. These young scientists are our richest source of fresh ideas, but they can least afford to wait for funding.

This is particularly true of younger physician scientists who have spent up to 10 years in clinical training before they can become independent scientists. While veteran scientists may survive intervals without funding, younger scientists with families are often forced to choose strictly clinical jobs that will never allow them to make important breakthroughs in biomedical science. When they quit research, they quit forever. This is most unfortunate, since these are the same individuals with insight that will allow basic scientific discoveries to rapidly be applied at the patient's bedside.

C. Dependence on Non-U.S. Scientists and the Mistreatment of Scientists.

Much outstanding research undertaken in U.S. laboratories is performed by scientists that came here from other countries. For reasons including increased restrictions on visas for scientists who wish to work and study in the U.S., the number of graduate students and scientists coming here is now declining. A rare but highly damaging issue has resulted from the mistreatment of scientists by governments. As Chair of the Committee on Human Rights of the National Academies of Science, I am familiar with cases from around the world including two devastating cases in the U.S.

Taiwanese-American scientist Wen Ho Lee was publicly referred to as "Spy of the Century" while shackled hand to foot for a year in solitary confinement. Dr. Lee was threatened repeatedly with execution if he did not confess to being a spy for the Peoples Republic of China. An independent review of the charges eventually brought his release with an apology in September 2000, but our standing with East Asian students has not been restored. *http://www4.nationalacademies.org/news.nsf/isbn/s08312000?OpenDocument*.

During the hysteria following the 2001 anthrax killings, a dedicated infectious disease specialist, Professor Thomas C. Butler, was arrested and charged with multiple federal felony counts when plague bacillus samples disappeared from his laboratory at Texas Tech University Health Sciences Center. Dr. Butler's work was entirely humanitarian, and no evidence of bioterrorism has ever been uncovered. Highly respected by his peers in the U.S. and admired by his colleagues in developing countries, Dr. Butler was hounded by the U.S. Department of Justice. While cleared of all charges related to bioterrorism, a conviction was obtained on confusing technical charges indirectly related to Butler's research budgets. Butler is now serving a two-year prison sentence while his appeal is pending. *http://www.fas.org/butler/*

D. Visibility of Scientists in U.S. Society.

The disappearance of scientists from public life is a concern. Interestingly, several of our Nation's founders included individuals who were leaders in science—Benjamin Rush [chemistry and medical biology], Thomas Jefferson [agricultural science], and Benjamin Franklin [electricity].

During my childhood, we would see scientists on the extremely popular Disney television program. Familiar to us was Wernher von Braun who demonstrated rocketry. Nobel Laureate Glenn Seaborg demonstrated the concept of a chemical chain reaction with mouse traps and ping-pong balls during a truly unforgettable program. At that time, Nobel Laureate Linus Pauling was widely recognized for his public efforts that launched the Limited Test Ban Treaty that still protects us from radioactive fallout in the atmosphere. Nobel Laureate Richard Feynman's books were popular reading.

E. Declining Scientific Awareness by U.S. Public.

A final and major concern relates to the decreasing level of scientific understanding by the U.S. public. I challenge the Members of this Senate Committee to ask your constituents to name even a single contemporary American scientist. But let me place some of the blame upon myself and my scientific colleagues. Except when challenged for negative reasons, we often consider ourselves too busy to engage in activities that may enlighten the rest of our society.

Widespread scientific ignorance significantly discourages young Americans from pursuing science. In my view, the need to educate our non-scientist citizens is just as important as the need to encourage future scientists. Recent controversies about the teaching evolution in high school biology appears to be a thinly disguised attempt by a minority to establish their particular religious viewpoint in publicly funded education.

Several parameters reflecting a decline in the national level of science understanding by the American public are apparent. Four hundred years after Galileo, one in five Americans still believes the sun rotates around the earth. Half of all Americans believe dinosaurs and humans coexisted in prehistory—apparently because they saw it on the *Flintstones*. U.S. school children consistently score below their counterparts in East Asia and often score below children in Eastern Europe. This must have something to do with the failure of more than half of all U.S. adults to read a single book [any book] in a given year.

III. Final Word—Nobel Banquet Speech.

Louis Pasteur said that "Chance favors the prepared mind." Having been raised in the post-sputnik era, I feel fortunate to have benefited from a high quality public school education and subsequently as a researcher funded entirely by the U.S. taxpayer. In closing I will share with you words from my Nobel Banquet Speech from two years ago.

> . . . in the 21st century, the boundaries separating chemistry, physics, and medicine have become blurred, and as happened during the Renaissance, sci-

> entists are following their curiosities even when they run beyond the formal limits of their training.
>
> The need for general scientific understanding by the public has never been larger, and the penalty for scientific illiteracy never harsher . . . Lack of scientific fundamentals causes people to make foolish decisions about issues such as the toxicity of chemicals, the efficacy of medicines, the changes in the global climate. Our single greatest defense against scientific ignorance is education, and early in the life of every scientist, the child's first interest was sparked by a teacher.
>
> Ladies and Gentlemen: please join me in applauding the individuals that foster the scientific competence of our society and are the heroes behind past, present, and future Nobel Prizes—the men and women who teach science to children in our schools.

Thank you.

The CHAIRMAN. Thank you, Doctor. I just wish more of my colleagues were here to hear that.

Dr. Cornell?

STATEMENT OF ERIC CORNELL, PH.D., SENIOR SCIENTIST, NATIONAL INSTITUTE OF STANDARDS AND TECHNOLOGY, TECHNOLOGY ADMINISTRATION, DEPARTMENT OF COMMERCE

Dr. CORNELL. Chairman Stevens and Members of the Committee, allow me briefly to introduce myself. My name is Eric Cornell. I work for the National Institute of Standards and Technology, NIST, in the Department of Commerce.

The CHAIRMAN. Could you pull the mike up just a little bit, please? Thank you. Did you press the button?

Dr. CORNELL. It's lit up. Is that a good sign? All right, good.

In 1992, I set out, at NIST, to make the world's coldest gas. I won't use the Committee's time to ramble on about my favorite topic, which is the physics of the ultracold. Suffice it to say that when you chill a gas down to within a millionth of a degree above absolute zero, the atoms in the gas all merge together to form one super-atom, which is called a Bose-Einstein condensate, a new state of matter. And it was for this achievement that I shared in winning the 2001 Nobel Prize.

What has Bose-Einstein condensation been good for? One example is that it is being used in an effort to develop a new generation of sensitive accelerometers to be used for remote sensing and for navigation by dead reckoning, as they do in nuclear submarines. In the long run, Bose-Einstein condensation is likely to be more important because of its role as a scientific building block, as a tool to help us understand and tame quantum mechanics. There are many examples of how taming quantum mechanics may make a big difference to our country in the coming couple decades. We'll probably hear a little bit about nanotechnology from Dr. Heath, but I'll tell you about one idea, called quantum computing.

Quantum computing is one of the most amazing concepts, in my opinion, to come out of the 1990s. Inside a computer, there are millions of tiny switches, called bits, that can be either on or off, one or zero, and these bits are the memory of the computer, and the bits are what a computer uses to make calculations. A quantum computer would have quantum bits. And the magic of a quantum bit is that, unlike a conventional bit, it can be simultaneously both on and off, both one and zero. It's a little spooky how that happens, and I'm not going to get into the math.

The power of this possibility comes in when you start stringing many quantum bits together with 60—if you add 60 ordinary computer bits all in a row, 60 ones and zeros, you could represent any number between one and about a quadrillion. With 60 quantum bits in a row, with each bit being both on and off at the same time, you can simultaneously represent every number between one and a quadrillion.

Why would you want to do that? A computational problem which is extremely important to our national security and our economy is this problem of breaking very, very large numbers up into their prime factors. Prime factor is at the heart of modern cryptography, and modern cryptography makes possible secure military and diplomatic communications, and is—also secure electronic transactions that are at the heart of our banking and finance systems. If the system of cryptography is threatened, it could cripple our economy in days or hours.

So, here's where the quantum computing comes in. Suppose you're a cryptographer and you want to know, for code-breaking reasons, the two numbers that multiply together to make up some very large number near one quadrillion. You want to know its prime factors. One way you could do that is take every number from one to a quadrillion and try and divide it into your huge number; and the ones that go evenly, those are the prime factors. But even for a very, very fast computer, a modern supercomputer, it takes a long time to do one-quadrillion divisions. That's why codes are secure. But imagine, instead, that you had a quantum computer, and you had quantum bits. What you do is, you take your 60 quantum bits, which simultaneously represent every number between one and quadrillion, and you use your quantum computer to divide your quantum number into this huge number you are trying to factor. In a single computational process, you can find out which of those quadrillion numbers divide in evenly; and so, you can find the prime factors of your huge number maybe billions of times—billions of times faster than you might be able to with a conventional computer, even a really fast one. The implications for secure communications and secure economic transactions are profound.

In biotechnology, quantum computing could find applications to really tough computing problems, like solving the problem of protein-folding in order to design a new generation of pharmaceuticals.

None of this is going to happen next week. We have no working quantum computer now. And don't count on there being one even in Fiscal Year 2007. The scientific and technical challenges associated with constructing quantum bits and stringing them together into an integrated quantum computer are immense. But I think we really need to try.

And why is it important that the U.S. conduct this and related research into quantum mechanics? As with any really cool problem, human nature dictates that there will always be curious people trying to come up with a solution, and quantum physics is no different. Teams from around the globe are laying the foundation for quantum computing now. If the U.S. heads for the sidelines, then we will watch others make profound discoveries that will ultimately improve the competitiveness of their industries and their quality of life.

I wish I could tell you what will be the big new industry of 2020. And, with respect, Senator, if I knew what would be the big new industry of 2020, instead of testifying here, I'd be starting my own quantum—my own venture-capital firm. I don't know what it's going to be. No one knows what's going to be the big new industrial idea of 2020. And that is why scientific research and discovery is so important. Without knowing for sure what the next big thing will be, we can remain cautiously optimistic that the next big thing, whatever it is, will be an American thing.

We could be optimistic, because over the last 50 years, as the American economy has benefited from many cycles of technology that emerges and subsides, one thing that hasn't changed has been America's lead in science/technology. But we have to be cautious, because, while our lead in science has remained in place for 50 years, the next 50 years are no sure thing. I think we should try and protect our lead.

And I thank you, Senator, for allowing me to testify before you today, and I'll be happy to take questions later on.

[The prepared statement of Dr. Cornell follows:]

PREPARED STATEMENT OF ERIC CORNELL, PH.D., SENIOR SCIENTIST, NATIONAL INSTITUTE OF STANDARDS AND TECHNOLOGY, TECHNOLOGY ADMINISTRATION, DEPARTMENT OF COMMERCE

Chairman Stevens and Members of the Committee, please allow me to briefly introduce myself and my research. My name is Eric Cornell and I was hired by the National Institute of Standards and Technology (NIST) in 1992 to do research in quantum optics. Management at NIST encouraged me to pursue a high-risk research program at the cutting edge of modern physics. I set out to make the World's Coldest Gas, building on techniques developed by my fellow NIST scientists, Drs. Jan Hall and Bill Phillips (who are both now also winners of the Nobel Prize in Physics).

Why would we want to make the World's Coldest Gas? There were several reasons. It turns out that cold gases are a useful environment for making extremely precise measurements, which is a capability at the heart of NIST's standards mission. Perhaps more important to me personally was that I knew that often times you can do the most exciting science if you can work right at the boundary of a current technological frontier, and one of science's key frontiers is the frontier of very low temperature. Every time we've been able to reach new heights (really "depths") in low temperature, exciting physics has followed.

I won't use the Committee's time to ramble on about my favorite topic, the physics of extreme low temperatures, but I will tell you that when a gas, made of atoms, gets colder and colder, those atoms, sure, move slower and slower. But there are also more subtle changes. For one thing, at room temperature, atoms act like little billiard balls, bouncing off the walls and off each other. But close to the very lowest possible temperatures, (known as "absolute zero") atoms stop acting like little balls and start acting instead like little waves. And at the VERY lowest temperatures, within a millionth of a degree of absolute zero, the atoms all merge together to form one super-atom-wave, a new state of matter called a Bose-Einstein condensate (BEC). Predicted by Albert Einstein back in 1925, the Bose-Einstein condensate had never been achieved until we finally found it at NIST in 1995. It was for this achievement that I shared (with my colleague from University of Colorado, Carl Wieman and with Wolfgang Ketterle) the 2001 Nobel Prize in physics.

Where has Bose-Einstein condensation led us, in the 10 years since we first created it? What, in particular has it been good for? BEC has found several direct applications, and in particular we and other research groups around the country are trying to develop precision accelerometers, gravitometers, and gyroscopes, to be used for remote sensing and navigation by dead reckoning. In the long run, BEC is likely to be still more important because of its role as a scientific building block, a tool to help us understand and tame quantum mechanics, and to put quantum mechanics to use on problems with relevance to our economy, our health, and our national security.

Let me share with you two examples of how the taming of quantum mechanics may make a big difference to our country in the coming two decades. The first is quantum computing.

Quantum computing is one of the most amazing concepts to come out of the 1990s. What puts the "quantum" in quantum computing is so-called "quantum bits." In an ordinary computer, there are millions of tiny switches, called bits, that can be either on or off, one or zero. The bits are the memory of the computer, and the bits are what a computer uses to make calculations. A "quantum bit," or "qbit," transcends the traditional requirement that a bit be either "on" or "off." A qbit instead can simultaneously be in a combination of "on" or "off." The power of this possibility comes in when you start stringing many qbits together. With ten bits in a row, with different combinations of "ones" or "zeros," you can represent any number between zero and 1023. With ten *quantum* bits in a row, each in a superposition of one and zero, you can simultaneously represent *every* number between one and a thousand.

Why would one want to do that? We can take as an example a computational problem which is extremely important to our national security and our economy—breaking large numbers up into their prime factors. Prime factors are at the heart of our cryptography systems, which allow for secure military and diplomatic communications, but also are at the heart of our banking and finance system. Businesses, banks, and increasingly ordinary consumers do not send cash or even checks for transactions—they send encrypted ones and zeros. If this system of cryptography is threatened, it could cripple our economy in days or hours.

Here is where quantum computing comes in. Suppose you want to find out what are the factors of 999,997. One way you could do that is to take every number from one to a thousand, and try to divide it into 999,997. The ones that go in evenly, those are the prime factors! Even for a modern computer, it takes a while to do one thousand divisions. Suppose instead your computer is made of quantum bits. What you can do is take your ten quantum bits, which simultaneously represent every number between one and a thousand, and try to divide that number into 999,997. In one single mathematical operation, you can find out if any of those numbers divide in evenly, and so you can find out if 999,997 is a prime number with one single operation instead of having to do one thousand of them.

For cryptography, you don't care about numbers like 999,997—you care about numbers that are a trillion trillion times larger, and what are the prime factors of *those* numbers. Using a quantum computer, you could answer that question in principle a trillion times faster than you can with an ordinary computer, even a so-called "super-computer." The implications for secure communications and economic transactions are profound.

There are other extremely difficult problems in computing, problems which are too hard for even the fastest modern computers to solve. One of these is the problem of protein folding, the way in which chains of amino acids bundle in on one another to form the parts that make up living biological cell. If this folding goes wrong, you get mad cow disease. The flip side is if you can learn to control and predict protein folding, you have a very powerful tool for designing the next generation of drugs. This is the sort of problem that a breakthrough in quantum computing could hugely impact, again by allowing one to do trillions of calculations all at once.

None of this is going to happen tomorrow. What I have left out of this whirlwind, geewhiz presentation of the potential of quantum computing is that there is no working quantum computer now, and don't count on there being one in 2006, either! The scientific and technical challenges associated with constructing quantum bits, and stringing them together into an integrated computer, are immense. In a modern conventional computer, there are literally billions of zero-one bits. A modern quantum computer would be so much more powerful than a conventional computer that it would not need billions of quantum bits in order to do amazing things. But it would need thousands of quantum bits. Currently the best experimental quantum computing teams are able to string together about four, maybe six quantum bits. Still, my own opinion is that quantum computing is such a powerful idea, it really must be explored.

Nanotechnology is a second important area that will benefit from the taming of quantum mechanics. I will leave the discussion of why nanotechnology is important for Dr. Heath's testimony.

So why is it important that the U.S. conduct this research? As with any problem, human nature dictates that there will always be curious people trying to come up with a solution. Quantum physics is no different. Teams from around the globe are conducting research trying to solve the riddle of quantum computing. If the U.S.

stays on the sidelines, then we will watch others make profound discoveries that will ultimately improve the competitiveness of their industries and quality of life. The big question is what is going to be the big new industry of 2020? If I knew the answer, I would not be here in front of you testifying—I'd be off setting up my own high-tech venture capital company instead. No one knows the answer for sure, that is why scientific research and discovery is so important. Without knowing for sure what the next big thing will be, we can remain cautiously optimistic that that big thing will be an American thing. The reason for optimism is that, over the last 50 years, as the American economy has benefited from many cycles of emerging technology, the one big thing that hasn't changed has been America's lead in science research. The reason for caution is that, while our lead has remained in place for 50 years, it need not remain for another 50. It needs to be nurtured!

I would like to thank the Committee once again for allowing me to testify before you today. I will be happy to answer any questions.

The CHAIRMAN. Thank you.

We've been joined by Senator Hutchison. Do you wish to make any comment today, Kay?

STATEMENT OF HON. KAY BAILEY HUTCHISON, U.S. SENATOR FROM TEXAS

Senator HUTCHISON. Let me say thank you. Thank you for holding this hearing. I am Chairman of the Space and Science Subcommittee of this Committee, and I have been very concerned that we are not doing enough in our basic education, K through 12, to assure that we have the prepared great minds for our universities to go into science, engineering, and also be the leaders in this field in the future. We are, I think, wise to take a very careful look at our situation and not think that because we're America, we will always be the best, because there are many other countries that are now putting more investment into education and into research. And I have been very active in promoting research in my state with our members of our National Academies of Science, Engineering, and the Institute of Medicine.

So, I welcome this. I intend, in my Subcommittee, to start looking at the National Science Foundation and what they are doing, and how we can make sure that they have the resources they need to go forward in the future and not only prepare our students, but direct the research that must be done for us to stay in the forefront. And I think what we have done with NIH, doubling the research capabilities of NIH, was a good thing that Congress did. And I think we need to start looking at the National Science Foundation for a real upgrade in their resources that we give them.

So, I thank you for coming and testifying. I intend to look at the record. I was a little late, but I intend to look at your statements, and welcome hearing from you and learning everything that you can tell us about what we can do to prepare our students and maintain our superiority in research in our institutions of higher education.

Thank you.

The CHAIRMAN. Thank you. It's nice to see you here.

Our next witness is Dr. James Heath, from the California Institute of Technology.

STATEMENT OF JAMES HEATH, PH.D., ELIZABETH W. GILLOON PROFESSOR OF CHEMISTRY, CALIFORNIA INSTITUTE OF TECHNOLOGY

Dr. HEATH. Senator Stevens and Senator Hutchison, it's a pleasure to be here today to give you my thoughts on the future of science with some perspectives of my own research.

For nearly a century now, the U.S. has been in the lead in developing science and technology. And we've done that by choosing hard problems, funding fundamental science at a level that lets us develop and nurture to build a foundation for technologies, and then by getting out of the way and letting free enterprise take over when the time is right.

A case in point is the National Nanotechnology Initiative, which has received significant support over the past several years from Congress. The NNI took a fledgling, but very promising, field and provided the resources to develop the foundation of that field.

That investment will definitely pay off. Though nanotech is now impacting industries ranging from information technology to healthcare, that impact will dramatically increase over the next several years. And I believe the U.S. will be in the lead in most areas, largely because of this NNI initiative.

It takes time. I can tell you, from my own research, one of the early discoveries in nanotech was something I did in my thesis work, the discovery of C60 and the fullerenes, which then led to things like carbon nanotubes, which led, then, to things like nanowires, et cetera. And if you look now, it's just the very early stage. Commercial ventures are beginning to come out of that. And that's about a 20-year timeline. Even with all of our resources and technology infrastructure, it's hard to beat that timeline.

As I look into the future, there are a number of major scientific challenges that are looming. But I believe at the head of that list is energy. And this is because energy consumption is the only consumable that directly tracks standard of living. The global energy consumption at the moment is in excess of 200 million barrels of oil per day, and that demand will likely double by 2050. Where is that energy going to come from? I don't think we have a solution through fossil fuels. And so, we'll have to look at alternative energy sources.

My mentor, the late Nobel Laureate Rick Smalley, called this the "terawatt problem." One terawatt equals 15 million barrels of oil. And what Rick meant was that any pathway that we take has to yield large energy dividends to be worthwhile.

I, personally, believe that solar energy is the only viable long-term solution. For example, 175,000 terawatts of solar energy impinge upon the Earth every day, and we need to collect about .03 percent of that to solve the problem by 2050.

However, this obviously has many other pathways, many other alternative energy sources. But, regardless of which pathway, or pathways, we take, the fundamental scientific challenges behind collecting, storing, and distributing energy are pretty tough. Scientifically speaking, there's no low apples on this tree. Even if Congress decided to act now, U.S. scientists and engineers are going to have their work cut out for them if they're going to solve this problem in time.

A second closely related challenge that we face involves getting our children engaged in science. And I'm going to echo my colleagues and Senator Hutchison's comments here. The World War II and Sputnik generations of American scientists largely developed the foundation of many of the things that are in our U.S. economy today, such as our biomedical industry, chemical industries, information technologies. The nanotech and biotech revolutions, which are happening now, are largely being developed on the shoulders of people that come here to get their Ph.D.s for graduate school.

As my colleague and—a well known nanotechnology researcher at Hewlett-Packard, Stan Williams, states, everybody in his lab over 40 years is American-born; everybody under 40 is Asian-born. China, in particular, has constructed several state-of-the-art universities, and they're continuing to do so. And they are currently producing many more scientists and engineers than we are. Asian countries, in general, are increasingly able to attract back their scientists and engineers by providing them with attractive laboratories, attractive resources, and exciting opportunities. In addition, the need of the Asian countries to meet the terawatt challenge is becoming increasingly acute, and necessity is the mother of invention.

If the U.S. is to maintain this competitive advantage as we move toward solving the technical problems of the 21st century, we have to take bold steps now to solve the underlying scientific and engineering challenges, and we also have to take steps to encouraging our children to take part in this future by becoming basically the developers of the future and taking fields in science and engineering.

Thank you.

[The prepared statement of Dr. Heath follows:]

PREPARED STATEMENT OF JAMES HEATH, PH.D., ELIZABETH W. GILLOON PROFESSOR OF CHEMISTRY, CALIFORNIA INSTITUTE OF TECHNOLOGY

Mr. Chairman and Members of the Committee, I appreciate the opportunity to give my thoughts on the future of science with perspectives from my own research. For nearly a century now the U.S. has provided scientific leadership to the rest of the world. We have done this as a Nation by taking bold steps to develop the scientific foundations in new areas, by sticking with the task until it was ripe for commercialization, and then by getting out of the way and letting free enterprise take over. A case in point is the National Nanotechnology Initiative (NNI), which has received strong and continuing support over the past several years. The NNI took a fledgling but tremendously promising field and provided the resources to develop the basic science for giving that field a foundation for growth. That investment will pay off. Nanotechnology is now impacting industries ranging from information technology to health care,[1] and that impact will dramatically increase over the next several years, with the U.S. in the lead in most areas.

As I look into the future, I see several major scientific challenges that are looming, but at the head of that list is energy. Energy consumption is the only quantity that directly correlates to standard of living. The global consumption of energy is now in excess of the equivalent of 200 million barrels of oil per day (MBOE), and that demand will more than double by 2050.[1] Where will all that energy come from? Fossil fuels will not meet this demand by themselves, and so alternative energy sources will have to be developed. The late Rick Smalley called this the "TeraWatt Challenge" (1 TeraWatt = 15 MBOE), meaning that any pathway we take must ultimately yield large energy dividends. I personally believe that solar energy is the only viable, long term solution (175,000 TeraWatts of solar energy impinge upon the

[1] Supplementary materials: Part I—Science-to-Technology Pathways; Part II: Energy Consumption; Part III: Production of Scientists in U.S. and Asia.

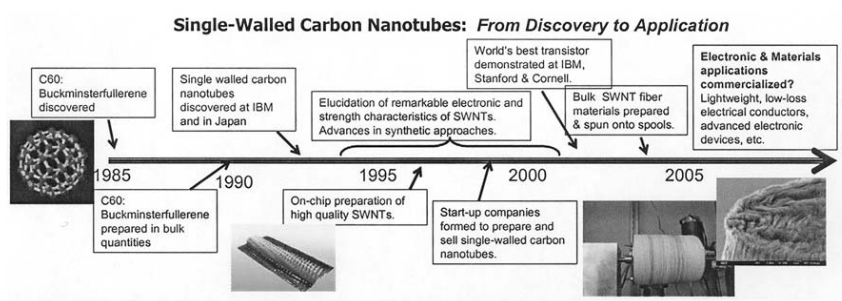
earth every day and we only need to collect ~.03 percent of that to solve this problem!), but it is not the only alternative. Regardless of which pathway or pathways we take, the fundamental scientific challenges behind collecting, storing, and distributing energy in usable forms are daunting. Scientifically speaking, there are no low apples on this tree. Even if Congress decided to act now, U.S. scientists and engineers are going to have their work cut out for them if they are to solve this problem in time.

A second closely related challenge that we face involves getting our children engaged in science. The WWII and Sputnik generations of American scientists largely developed the information technologies and biomedical and chemical industries that provide for much of the U.S. economy today. The nanotech and biotech revolutions are, in large part, being developed by foreign-born scientists that immigrated to the U.S. for graduate school. Stan Williams, a leading nanotechnology researcher at Hewlett Packard, states that “Everybody in my lab over 40 is U.S. born. Everybody under 40 is Asian born.” China, in particular, has constructed several state-of-the-art research universities over the past several years, and they are currently producing many more scientists and engineers than we are. [1,2] Asian countries, in general, are increasingly able to attract their own scientists back from the U.S. by providing them with exciting opportunities and significant resources. In addition, their need to meet the TeraWatt Challenge is becoming increasingly acute, and necessity is the mother of invention. If the U.S. is to maintain its competitive advantage as we move towards solving the scientific and engineering challenges of the 21st century, then we must take bold steps now to solve the underlying scientific and engineering challenges. We must also take strong steps towards encouraging and preparing our children to actively participate in developing this future by becoming the scientists and engineers who will make it happen.

Supplementary Material

In this supplement I provide two examples of relatively modern discoveries, the development of which was aided by the National Nanotechnology Initiative (NNI), and which will lead to a variety of commercial applications within the next decade or so. The point of these examples is to illustrate that even today, with all of the scientific and technological infrastructure that is in place in the U.S., the timeline between initial discovery and initial commercial application remains around 15–20 years. Both of the examples provided, single-walled carbon nanotubes and semiconductor nanowires, constitute the enabling discovery that can support a number of technologies. As a result both classes of materials have also received significant attention and federal investment worldwide.

As we move towards addressing the emerging problems of this century, it will be necessary for us to not only move boldly towards solving those problems, but to also stay the course and allow for the development of the critical scientific discoveries into viable technologies. With respect to the energy problem highlighted in my testimony, it is worth noting that many discoveries that have been supported by the NNI (including carbon nanotubes and nanowires) will likely play key roles in terms of developing the ultimate solutions.



Single walled carbon nanotubes are currently being developed, within both academic and industrial settings, as:

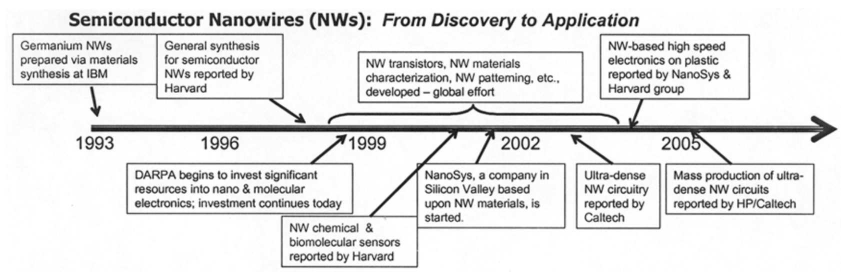
- lightweight electrical conductors (can impact the energy problem)
- integral components in video monitors
- high speed, low power electronics devices

[2] National Science Board, Science and Engineering Indicators (2002 and 2004).

- chemical sensors for applications in many arenas including bioagent detection
- lightweight, ultra-strong structural materials (e.g., kevlar replacements).

The second example, that of semiconductor nanowires, is also characterized by an equally broad and diverse set of applications. Depending on the application, these materials are currently being investigated in both academic and commercial settings. Applications include:

- High-speed electronic and optical devices that work on plastic substrates
- Adhesives with an unusual and enabling combination of properties
- BioSensors within chip-based tools for the early diagnosis of cancer and other diseases
- Electronic circuitry that significantly extends the Moore's Law scaling of electronic devices.
- Ultra-efficient thermoelectric devices (refrigerators and power-recovery devices) (*can impact the energy problem*)



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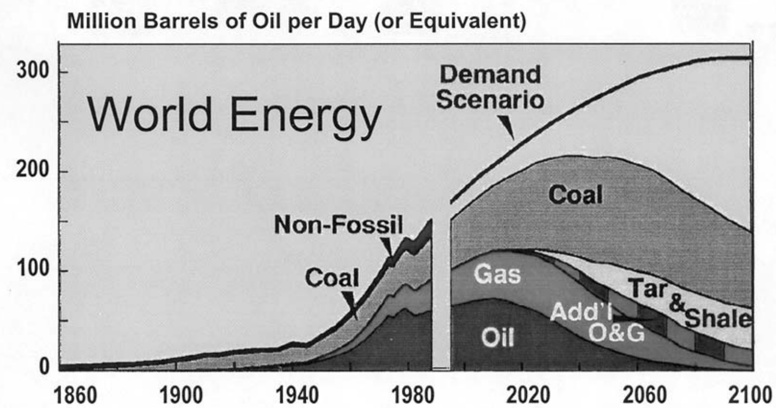
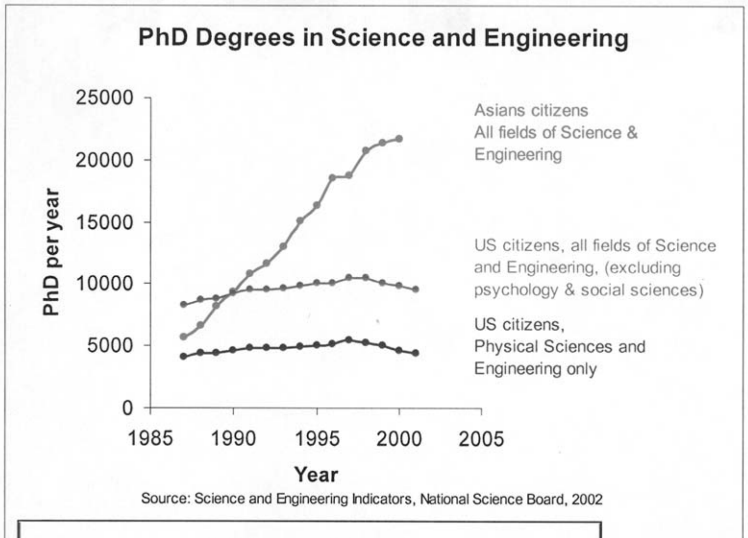
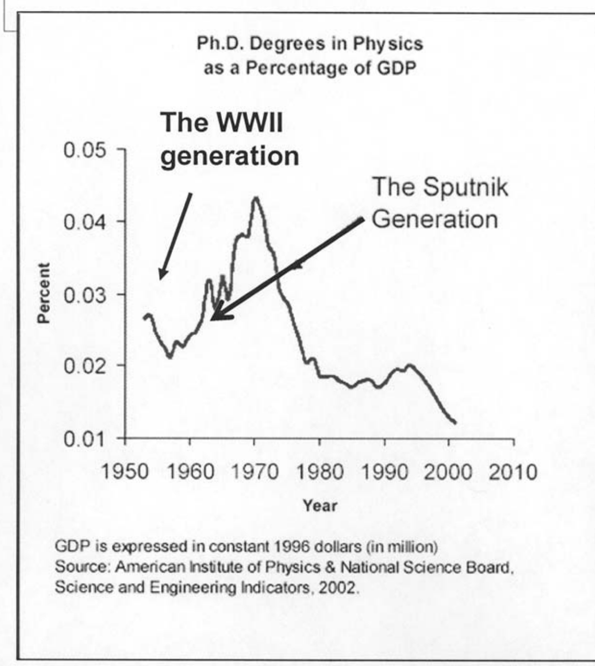


Source: John F. Bookout (President of Shell USA) ,"Two Centuries of Fossil Fuel Energy" Int'l Geological Congress, Washington DC; July 10,1985. Episodes, vol 12, 257-262 (1989).

Supplement III. Data on the Production of U.S. Scientists and Engineers with a comparison to Asia.





The CHAIRMAN. Thank you very much, Dr. Heath.

Our last witness is Professor Samuel C.C. Ting, of the Massachusetts Institute of Technology.

Dr. Ting?

STATEMENT OF SAMUEL C.C. TING, PH.D., THOMAS DUDLEY CABOT PROFESSOR OF PHYSICS, MASSACHUSETTS INSTITUTE OF TECHNOLOGY

Dr. TING. Good morning, Senator Stevens, Senator Hutchison——

The CHAIRMAN. Can you pull that even closer toward you? Doctor, please?

Dr. TING. I'm Samuel Ting, from MIT. I was born in Michigan, graduated from the University of Michigan.

I've been doing experimental physics all my life, and have always led large international collaborations in accelerator laboratories in the United States and Europe and the Space Shuttle and, in the future, on the Space Station.

When I first started, I worked in Hamburg, Germany. After that I returned to United States, and then worked in Hamburg again; and for 20 years, I worked in the largest accelerator in the world, the 16-mile circumference electron-positron collider, in Geneva Switzerland. In the last 10 years, I've been working closely with Johnson Space Center on the Space Shuttle and, in the future, on the Space Station.

When I first started, my group had ten physicists. Now, there are 600. When I first started doing experiments, the experiment cost $100,000. In my two latest experiments, they each cost one billion dollars, involving 16 countries.

What I would like to call to your attention is the importance of fundamental science on the International Space Station, a subject often not mentioned in the United States. Let me present, in a very simple way. In space, there are two types of cosmic rays: One type has no charge, light rays. Light rays have been studied by satellites, the Hubble Telescope is an example. Over the last 40 years, four Nobel Prizes have been given for the study of light rays. But, beside light rays, there are particles that carry a charge. No matter how large an accelerator you make, you can never make higher energy than the cosmos. To study the cosmos will probe the foundations of modern physics. For 10 years, I have led an experiment to put a magnetic device, like the ones appearing in accelerators, on the Space Station. The Space Station, because of its size and power, is the only way to do such an experiment.

Senator HUTCHISON. Why is the Space Station the only place?

Dr. TING. Because it supports large weight and generates high power. Because it provides an enormous amount of electric power, and because it can stand the weight.

So, working on this experiment with me, the 16—there are 16 countries on this experiment. I think Senator Hutchison will be pleased to know in this experiment on the Space Station there are, in United States, the Johnson Space Center, MIT, Yale, and then nearly all the countries in Europe, Russia, China, Taiwan, and Korea. In total, there are 16 countries, 500 physicists. In 10 years, a total of about $1.2 billion has been spent, mostly from European countries. And it's perhaps because of this, that this experiment is seldom known in the United States. But most of the cost is done by the Europeans.

To do such an experiment, we have developed an enormous amount of new technology for exploration. The superconducting magnet is one, which provides a way to protect astronauts on their way to Mars and on the moon. A precision silicon detector is another. And these detectors provide unheard-of resolution to identify particles. And these are mostly done through a national effort in Switzerland and Italy. Now the experiment from the 16 countries is completed after some $1.2 billion, and now is being assembled in Europe.

What is the physics? One of the physics is the search for the universe made out of antimatter. What is antimatter? You know there's an electron. If you go to the hospital, you have a PET scan, called positron tomography. The positron is the antimatter of the electron. If the universe has come from a Big Bang, before the Big Bang there was a vacuum. So right at beginning of a Big Bang, if there's matter, there must be antimatter to balance it off. Now the universe is 15 billion years old. Now we ask a simple question, Where is the universe made out of antimatter? If the universe comes from a Big Bang, there must be a universe made out of antimatter.

The physics of antimatter probes the foundations of modern physics. And it is the main research topic for the next generation of accelerators worldwide. People discuss the Space Station. Very few people in the United States discuss how important it is for the Space Station to address the fundamental issues of science. Because no matter how much money is spent on Earth, you are never going to build a larger accelerator than what you could do on the Space Station.

I have two things I would like to call to your attention. The first is the importance of U.S. participation in international collaborations. My last two experiments each cost more than a billion. So, the size and cost of modern physics experiments for accelerators and space make it mandatory to seek international collaboration. Rather than competing, it is much more efficient to collaborate together toward a common goal.

My second observation is the importance of U.S. maintaining its international commitment. The cancellation of a project located in Waxahatchie, the superconducting supercollider, had a devastating effect on the U.S. science community, shifting the focus of particle physics research to Europe and Japan. By the end of the decade, more than half of the U.S. high-energy physicists will be working in Europe and Japan unless we make a effort to build the next accelerator in the United States.

Another thing which is also ignored is the potential breakthrough in science by the next generation of space experiment that's managed by NASA, the JDEM, GLAST, and AMS must not become victims of expediency. These experiments are international collaborations led by United States physicists with major foreign support. It is important NASA be strongly supported to honor its international commitments and to maintain its credibility. But, most important, the Space Station is a visible symbol of American commitment to science and to international collaboration, and it is a vital part of our national legacy of exploration and excellence.

And I thank you for your attention.

[The prepared statement of Dr. Ting follows:]

PREPARED STATEMENT OF SAMUEL C.C. TING, PH.D., THOMAS DUDLEY CABOT PROFESSOR OF PHYSICS, MASSACHUSETTS INSTITUTE OF TECHNOLOGY

Mr. Chairman, Distinguished Members of the Committee, Ladies and Gentlemen:

It is a privilege to address this distinguished gathering on the important issue of the future of science in the United States. I am an experimental high energy physicist. I was born in Michigan and received my university degrees at the University of Michigan. Throughout my career, I have led large international collaborations conducting experiments in accelerator laboratories in the United States and Europe as well as on the Space Shuttle. Currently, I am leading a large international team of 500 physicists from 16 countries who are completing an experiment to be deployed on the International Space Station (ISS). My research has always been supported by the U.S. Department of Energy (DOE), by M.I.T. and I have always received strong worldwide support (Finland, France, Germany, India, Italy, Korea, the Netherlands, Pakistan, Portugal, Peoples Republic of China, Russia, Spain, Switzerland, Taiwan . . .). My testimony is based on my own experience and observations in large-scale particle physics research and large international collaborations.

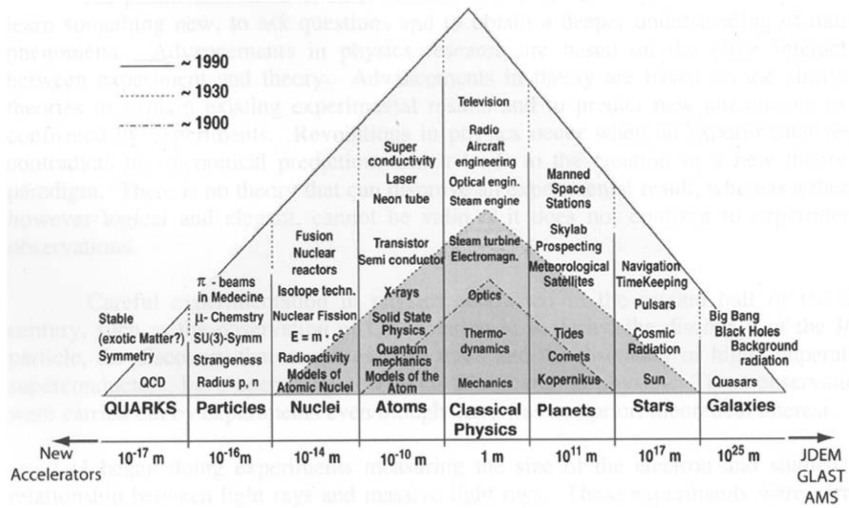
In the 21st century the United States is enjoying unprecedented levels of technological development such as in the fields of communication, computers, transportation, medicine, etc that have had dramatic effects on the quality of life. What is often forgotten is the fact that the foundation of these achievements was laid down some time ago by scientists who were driven by intellectual curiosity and not by economic concerns. History has taught us that support for basic research in science advances other areas of achievement in our society such as education and industry.

The German physicist and philosopher Christopher Lichtenberg wrote in his diary 200 years ago:

> "To invent a remedy against toothache which would take it away in a moment might be more valuable than to discover another planet . . . But I do not know how to start the diary of this year with a more important topic than with the news of the new planet."

It was the planet Uranus, discovered in 1781 and which was recently investigated more closely by the Voyager spacecraft. Even at that time, one was confronted with a problem which is as important today as 200 years ago: should one build satellites to explore the universe, and accelerators to investigate the microcosm at a time when burning problems like energy production, disease and overpopulation, etc . . . trouble our society?

The following graph illustrates the relationship between basic physics research and its direct application to daily life. The inner triangle shows the area of basic research in the 1900's covering the scale from atoms to planets. The shaded triangle shows the areas of basic research in the 1930s which extended the scale from the nucleus to stars and its applications derived from earlier research. The outermost triangle shows the area of basic research today. It covers the scale from the size of quarks to galaxies. The outermost triangle also includes some of the key technology developed based on results of previous research.



The above graph demonstrates how fundamental research has provided the basis for technology in the past. Fundamental research started from human dimensions to explore on one side larger objects, i.e., the universe with its planets, stars, galaxies, etc. and on the other side, it has penetrated into the microcosm discovering ever smaller building blocks of matter, i.e., atoms, atomic nuclei, protons and neutrons, quarks, etc. Out of classical physics came the steam engine, photography, electrical engineering, radio, TV, airplanes, etc. The atomic world and quantum physics, which was necessary to understand it, delivered many new materials like semiconductors and superconductors with their many applications, i.e., the transistor, neon lamps, lasers, microprocessors, computers, etc. The world of atomic nucleus gave rise to applications like the isotope technique in medicine, material testing and fission energy in nuclear reactors. One notices that in the past, the pyramid has grown with new applications increasing its height while fundamental research continuously widens its base. The role of basic research finds itself always on the outermost corners of the pyramid and hence is sometimes blamed for being too remote from daily life. Only after some time when applications grow and the public becomes acquainted with the strange new phenomena they seem to become more "real." There is no reason that the pyramid should not continue to grow in the future and technological quantum jumps, fed by new discoveries, can be expected. Of course, the time it takes from the discovery of a new phenomenon to the introduction of its application into the market is still of the order of 20 to 40 years. Such a period is too long for many politicians and industrialists.

But research does not continue in a straight line. Errors are an integral part of the effort when penetrating into unknown territory and predictions are difficult. Hence, basic research needs sufficient freedom and a long perspective.

The prime motivation of basic research is human curiosity—the innate passion to learn something new, to ask questions and to obtain a deeper understanding of natural phenomena. Advancements in physics research are based on the close interaction between experiment and theory. Advancements in theory are based on the ability of theories to explain existing experimental results and to predict new phenomena to be confirmed by experiments. Revolutions in physics occur when an experimental result contradicts the theoretical prediction, which leads to the creation of a new theory or paradigm. There is no theory that can disprove an experimental result, whereas a theory, however logical and elegant, cannot be valid if it does not conform to experimental observations.

Careful experimentation in physics conducted in the second half of the 20th century, such as the observation of CP violation in K decay, the discovery of the J/psi particle, the discovery that neutrinos have mass and the discovery of high temperature superconductors, have opened up new fields of research in physics. These observations were carried out by experiments even though there was no *a priori* theoretical interest.

I began doing experiments measuring the size of the electron and studied the relationship between light rays and massive light rays. These experiments were carried out at the German National Accelerator (DESY). This was followed by an experiment at the Brookhaven National Laboratory leading to the discovery of a new form of matter. Subsequently, I returned to DESY to work on the highest energy electron positron collider, PETRA, leading to the discovery of gluons. In recent years I have led two international collaborations, one on the ground and one in space.

1. From 1982 to 2003, I led a 19 country, 600 physicist collaboration at the European Organization for Nuclear Research (CERN) in Geneva, Switzerland. CERN's 16 mile circumference Large Electron Positron Collider created conditions close to those at the beginning of the universe. One of the purposes of our experiment was to search for the origin of mass. Even though the experiment was constructed at the height of the Cold War, it was the first large collaboration between the USSR, China, Europe and the United States and represented the largest contribution from the USSR to an international collaboration in physics research.

2. From 1994 to the present, I have been leading the AMS international collaboration building an experiment for deployment on the International Space Station. AMS will use the ISS as a unique orbiting laboratory to seek answers to the fundamental questions of modern physics and cosmology.

These two experiments are multi-billion dollar projects. Even though most of the financial and technical support came from outside the U.S., these experiments have been regarded by the world scientific community as U.S. DOE led experiments.

The completion of the International Space Station, with its unique capability to support complex modern accelerator type experiments, will be a truly outstanding laboratory facility of which the United States should be very proud and utilize to its full extent. The ISS will provide a base to do experiments without hindrance from the dense Earth atmosphere and gravity. On Earth we live under 100km of air, which is equivalent to 30 feet of water, and this absorbs all the primordial charged particles and high energy gamma rays. The highest energy particles are produced in cosmic rays and it is through understanding the nature of primary charged cosmic rays that clues on the foundation of modern physics will be revealed such as the existence of the universe made out of antimatter, the origin of dark matter, and the existence of strangelets, etc.

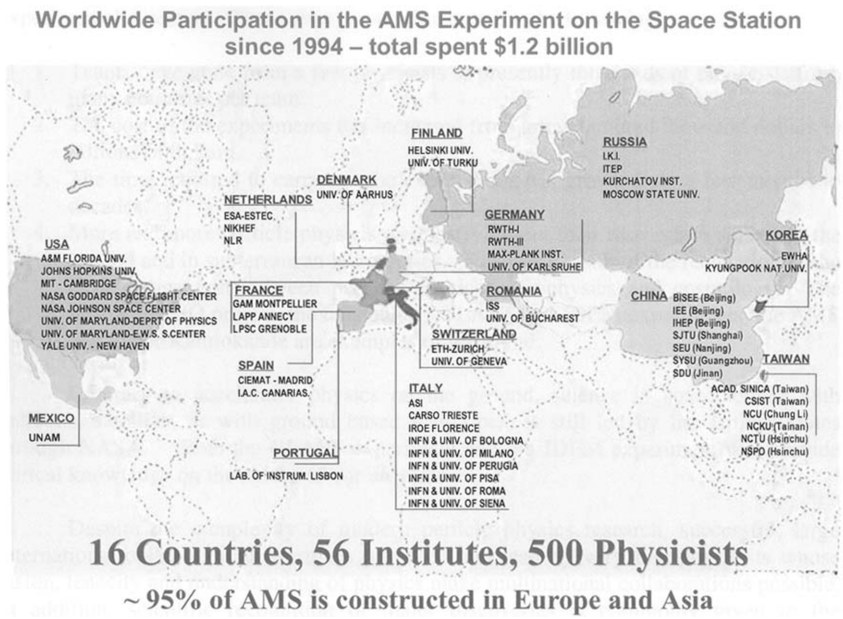
If the universe came from a "Big Bang", at the beginning there must have been equal amounts of matter and antimatter. The search for an explanation for the absence of antimatter is the main research topic of the current and next generation of particle accelerators world-wide. The existence of dark matter has been one of the mysteries of modern particle physics and cosmology—why so much of our universe is not observable. All matter on earth is made out of only two of the six known kinds of quarks. Strangelets are new types of matter composed of three types of quarks which should exist in the cosmos. These questions touch upon the foundations of modern physics and the AMS experiment will provide for the first time a most sensitive means to answer these questions.

The AMS experiment is one of the largest international collaborations supporting fundamental science on the space station. Indeed, 95 percent of the $1.2B cost to build AMS has been funded by sources outside the U.S. It uses the technology developed in particle physics modified for space application. AMS uses a large superconducting magnet for the first time in space research. The purpose of the magnet is to distinguish matter from antimatter by observing positive or negative charges tracked in the magnetic field.

As an important byproduct of the science to be produced by AMS, the experiment will also provide important applications for the U.S. space exploration program. These include precise mapping of cosmic ray radiation background as well as the use of superconducting magnet technology for propulsion, energy sources and to provide safe, light weight and complete radiation shielding for manned interplanetary space travel. Out of the 27,000 manned days spent in space, only 1 percent (303 manned days during the Apollo era) was spent outside the magnetosphere. This, together with the fact that our current knowledge of the nature of radiation from dangerous heavy ions is limited, makes the precision study of the nature of cosmic rays and their dependence on energy and time important input for future long distance human space travel or sustaining long periods on the moon.

Current estimates by NASA indicate that without protection, astronauts will receive lethal doses of radiation on a three-year trip to Mars. Superconducting magnet technology offers the only effective way to protect astronauts from this hazard because of its capacity to deflect radiation away with its strong magnetic field.

The following graph presents the AMS international collaboration.



At the beginning of my career, experimental particle physics research was dominated by the United States. Very few American physicists worked in Europe. Gradually, with improved economic conditions, other countries realized the importance of supporting fundamental research and the benefits to science, education and technological growth inherent in such investments. The European Organization for Nuclear Research (CERN) in Geneva, Switzerland was founded when many European countries made the decision to pool their resources to build larger and more powerful accelerators and to provide technical infrastructure for their physicists. Later Germany and Japan built their own unique accelerator and research facilities. The cancellation of the U.S. Superconducting Supercollider project (SSC)—mostly due to its own mismanagement—contributed significantly to the loss of U.S. dominance in the field forcing large numbers of U.S. physicists to go to Europe or Japan to conduct their research. Indeed, some of the most important discoveries in particle physics such as the discovery of the intermediate vector bosons, the discovery of gluon jets, the discovery of neutral currents, and the discovery that neutrinos have mass were all done at foreign facilities. All these major discoveries, though having had significant U.S. participation, are credited justifiably to European and Japanese laboratories and recognition given to the principal investigators. The only exception was the discovery of the gluon jet which was recognized as DOE/MIT discovery.

The nature of experimental particle physics research has changed dramatically because of the limited availability of research facilities and the increasing complexity of experimental detectors. These changes are illustrated in the following:

1. Teams have gone from a few physicists to presently thousands of physicists from many countries per team.
2. The cost of the experiments has increased from a few hundred thousand dollars to billions of dollars.
3. The time required to carry out the experiments has grown from a few months to decades.
4. More and more particle physicists are carrying out their research in space, on the ground and in subterranean laboratories. This is the result of the realization of the close connection between particle physics, astrophysics and cosmology. The brilliant LIGO project, the outstanding GLAST and JDEM experiments, the AMS and Super Kamiokande are examples of this trend.

Contrary to accelerator physics on the ground, science in space, either with balloons, satellites or with ground based telescopes, is still led by the United States through NASA. Both the GLAST experiment and the JDEM experiment will provide critical knowledge on the nature of our universe.

Despite the complexity of modern particle physics research, successful, large international collaborations are often proposed and lead by very few physicists whose vision, tenacity and understanding of physics make multinational collaborations possible. In addition, scientific recognition of major discoveries is commonly given to the laboratory at which the discovery was made. SLAC, Fermilab, Brookhaven, CERN and DESY are recognized as successful laboratories because so many major discoveries have been made in their facilities. In addition, even though modern groups may have thousands of physicists, a truly outstanding and dedicated young physicist will distinguish him or herself and be easily identified by the physics community. This is because the advancements in physics have always come from the efforts of a few people with unconventional ideas and not from public consensus. Indeed, one cannot vote on physics issues.

Having worked in laboratories in Europe, the United States and in space, I have the following observations on how the U.S. can maintain its world leadership in science in the future. These include:

1. The importance of U.S. participation in international collaborations.

The size and cost of modern physics experiments for accelerators and space make it mandatory to seek international collaboration. It is no longer possible or necessary for a single country to have the best technology in every field—an example is superconducting magnet technology. The world's best superconducting magnet technology is now in Europe and Japan and not in the U.S. In addition, the days of competing experiments with similar goals is a luxury we can no longer afford. Rather than competing, it is much more efficient to collaborate together towards a common goal.

2. The importance of the U.S. maintaining its international commitments.

In Europe when a research instrument, such as an accelerator or spacecraft, is approved by a government or governments, it is almost always carried out to a successful end. In the United States, the cancellation of ISABELLE and the SSC had a devastating effect on the world science community resulting in close to 500 U.S. physicists presently working at CERN on the Large Hadron Collider (LHC).

3. Providing strong support to important U.S. led international collaborations which connect particle physics, astrophysics and cosmology, such as JDEM, GLAST and AMS.

These large international collaborations are led scientifically and technically by the U.S. These experiments have the potential of making groundbreaking discoveries in physics. This potential for major breakthroughs in science performed on the ISS must not be underestimated nor become the victim of expediency. The ISS is a visible symbol of American commitment to science and international collaboration and is a vital part of our national legacy of exploration and excellence. NASA should be strongly supported to carry out its world class experiments and to fulfill its commitments to our international partners.

4. The importance of ensuring that some of the future key international projects, such as the next generation of accelerators, be located in the U.S.

The advancement of physics is not determined by the amount of data taken and the number of papers published. The advancement of physics is driven by unpredicted and fundamental discoveries. The next generation accelerator will require enormous amounts of technical development in instrumentation, electronics, material, data storage and analysis as well as a large team of engineers and scientists. The laboratories at which discoveries are made traditionally are given the recognition and credit. For the U.S. to regain its leadership in particle physics it is important to ensure that the location of the next generation of accelerators be in the United States.

5. The importance of continuing strong support to basic research in universities to train students and to attract the world's best minds to work in the U.S.

Most of the major discoveries in experimental particle physics were not predicted at the time of the original justification to build the accelerator was formulated but came about unexpectedly and often in contradiction to prevailing theory or public opinion. A glance of the Nobel Prizes awarded to physicists will reveal that most of the prizes were given to university professors. This is because universities grant sufficient academic freedom to promote creativity and originality. Today fewer students in the United States are studying physics unlike our European and Asian counterparts. To strengthen science education in primary and secondary school as well as universities will enhance the numbers of students studying science and will ensure a better informed public on science issues.

I thank you for your attention.

The CHAIRMAN. That's staggering, really. I have in mind taking your speech and repeating it on the floor of the Senate one of these days, Dr. Ting. I'm really grateful to you for coming.

This week, we have had a visit from the group that was working with Norman Augustine, who used to be the head of Lockheed Martin and is on the President's Council of Advisors on Science and Technology, and they have brought to us a report now that's being distributed to every Member of the Congress. I don't know if you're familiar with it. It's called "Rising Above the Gathering Storm." It is a very important, I think, presentation, and calls upon Congress to respond to the same points that you are making here, only yours is more of a scientific approach; this is an approach to our basic inspiration to do something about the underlying problem of the education of our people. It points out, for instance, that we are in a very difficult situation with regard to our educational process, because, for instance, in China—in 2004, China graduated 500,000 engineers; India, 200,000; and America, 70,000. And it has a whole series of presentations to us about the necessity to rekindle the support of the Federal Government for basic education for scientists.

Of course, you go beyond that; and that is, basic support for scientists once they're trained. And I think that cause needs to be very highly articulated, also. The difficulty that we have is that we seem to be losing our willingness to support the educational process as we have in the past. And I think we will have to reassess our current approach to education if we're going to meet this challenge that they have given us. They've had two key challenges to us to deal with beginning a new approach to education from kindergarten to 12th grade, and then, beyond that, the concept of higher education to respond to our needs for the future.

I don't know if you all have seen this report. If you haven't, we'll be glad to get it for you. But I'm very impressed with your presentation here.

Can you tell us—and it's sort of obtuse, I guess, but, where do you get your financing for the research you're doing now?

Dr. Agre?

Dr. AGRE. Our laboratory was entirely funded by the American taxpayer in the form of NIH grants. As a student, I was able to stay in a laboratory. After graduation, during my internship, support from U.S. taxpayers in the form of an NIH training grant. And most of my colleagues, the support is entirely from the U.S. taxpayers. And that includes most of the salaries of the individuals.

The CHAIRMAN. Dr. Cornell?

Dr. CORNELL. Support in my lab comes mainly from the National Institute of Standards and Technology and from the National Science Foundation, and a small amount of seed money from a private citizen in the State of Colorado.

The CHAIRMAN. Dr. Heath?

Dr. HEATH. I direct a cancer center that is aimed at translating nanotechnologies to clinical applications, and that's funded by the

NCI, and I also get a significant amount of funding from the DOD, and about 10 percent from private enterprise.

The CHAIRMAN. And Dr. Ting?

Dr. TING. I'm quite expensive.

[Laughter.]

Dr. TING. Throughout my career, I have been supported by the United States Department of Energy, by MIT, and also by Johnson Space Center, but most of my support, the vast majority of my support, comes from Europe—from Germany, from Switzerland, from France, from Italy, from Russia—my experiment was the largest overseas investment from Russia—from China, from Taiwan, from many, many countries, even through the foreigners—foreign countries provide the vast majority of support, because these experiments were proposed by me, executed by me, they are known as U.S. experiments.

The CHAIRMAN. This report shows that the cost of one chemist or one engineer in the United States, as compared to other countries. A company can hire, for one chemist, five chemists in China; or 11 engineers in India for one engineer in the U.S. One of our problems is the level of our lifestyle and the level of our cost base. What's your answer to that? How can we compete, if that is the case, when these foreign people are currently turning out so many more engineers and scientists than we are? In effect, Dr. Ting, you're getting, as they would say, a bigger bang for the buck over there, aren't you? We have a problem of cost here at home, in competing, as well as the education of our people. Am I right?

Dr. TING. Yes. Senator, I can answer in the following way. Why this field of high-energy physics, which used to be totally dominated by the United States, and now it's dominated by Europe and Japan, it is because the research discoveries from this field often make a quantum jump in technology. A hundred years ago the focus of high-energy physics was the discovery of the electron. In the 1920s it was the atom. In the forties it was the nucleus. And these, even though at that time it was fundamental research, now have completely changed our lives. And it's because of that, countries like Germany, like Japan, like Switzerland, invest so much in this field. I think that's the way I can address this to you, sir.

Dr. CORNELL. Senator?

The CHAIRMAN. Yes sir, Dr. Cornell.

Dr. CORNELL. Could I address that question?

I think it's important to look historically. We used to do a lot of injection plastic molding here. Now it's done in the Philippines. And it's true that your basic unit of chemist is going to be cheaper in India than it is going to be here. I think the strategy we should adopt as a country has been what we've always done, which is to define the cutting edge to be ours. And we continue to have that, although in terms of raw chemists per dollar, it's cheaper in India, in terms of raw internationally leading chemists per dollar, we remain almost really the place to go, the place where Indians and Chinese and so on come if they want to get research education at the very, very highest end, it's still here in the United States. And that, I think, is where we preserve our lead in the high-quality niche market of science, if you like.

The CHAIRMAN. We also have figures from this study about the number of foreign students that are in our own universities. They are—the majority of them are from foreign countries and are returning to their countries now. In the past, there was an incentive to stay here. Now there seems to be an incentive for them to get their education here and go back to their countries, or other countries where there are centers of research, such as Dr. Ting has outlined. What would be your suggestions on how to deal with that, as far as Congress is concerned?

Dr. CORNELL. The international students who come here and then choose to remain represent a vast influx—injection of human capital into the United States. It's a marvelous resource. And we should do what we can to hold onto these people. And, in particular, I think we should avoid—we should make sure that they feel welcome here—avoid getting them tangled up in, for instance, INS red tape unnecessarily.

The CHAIRMAN. You should all come and go fishing with us. Jim knows. I go from the esoteric to the sublime and talk about why we're sending all our money overseas for oil and natural gas and not having the development money that comes from those two by developing our own resources. We currently send out of our country more of our own gross national product for energy than any other nation in the world. And, as a consequence, our money goes over there, we have to sell our goods cheaper, we have to export our scientists. We don't have the economic base we used to have, because we refuse to develop energy here at home. Jim and I are going to have that conversation again this summer, I hope. But, sometime, we have to find a way to deal with it.

Senator Hutchison?

Senator HUTCHISON. Thank you very much, Mr. Chairman.

As Chairman of the NASA part of our Committee, I can tell you that I am fighting so hard to keep the Space Station—fully finish the Space Station and make it a vehicle for scientific research. Today, right now, Michael Griffin tells me that the only research that they can afford to do in the NASA budget is directly related to living in space and the effects of space life on the body. That's basically what he's saying.

Now, we're in the process of passing a new authorization bill for NASA, and in that bill we have introduced the concept of putting a national laboratory designation on the Space Station. The reason I did that is because I am trying to get money from other sources to assure that we don't eat our seed corn. You have made, Dr. Ting, the best speech I have ever heard on this subject, and I'm going to send it to Michael Griffin to—and Michael Griffin agrees with us, let me say—but what Michael Griffin is trying to do is save our space exploration project, the whole NASA program, and he is trying to put the shrinking dollars that he is getting into the areas that we must have. So, I'm not critical of him, but I am looking for creativity to assure that we don't shrink the Space Station and the scientific part of the NASA operation to the point that we might as well throw it away. Because if we're going to do it halfway, we will do nothing.

So, I'm going to ask you a couple of questions.

First, do you think the concept of a national laboratory designation, where we can get both private money and university money, in addition to NASA money, is a viable alternative for saving the Space Station for real scientific research? And—but let me just finish and—ask you to answer that, and then I have another line of questioning, if the Chairman will indulge.

Dr. TING. Thank you, Senator. I have worked for many years with NASA. It is a good organization, and I had a very good experience working with them. Exploration, of course, is very important. Like you said, once you spend close to $100 billion to build a Space Station, and if you don't use it—if you don't use its potential to make fundamental discoveries in science, it's—just like you said, it's a total waste. And so, to have a national laboratory, it's extremely important.

I only want to submit to you, I know Europeans, Asians are very, very interested in working on the Space Station, so you may want to take this into consideration, to invite the Europeans, our allies from Europe, to work—even the French want to work on the Space Station. It's a fact that is seldom brought up in the United States. What is the fundamental science, in physical science, you can do? It's because you have left the atmosphere, and you have the highest-energy particles, and you can never produce a accelerator on the ground to create a condition of cosmos. It's a unique thing.

Thank you, Senator.

Senator HUTCHISON. Dr. Ting, let me just ask you, or anyone on the panel, do you have any other creative ideas about ways that we could promote that science research on the Space Station in the shrinking budget environment in which we find ourselves, other than, of course, increasing the money and making it a priority, which is what we will try to do, and my national lab proposal—but is there anything else that you would suggest?

Dr. TING. Well, if you allow me, Senator, money, of course, is important, but to let it be known, scientists from Europe, scientists from Asia, once they've made a proposal to carry out an experiment on the Space Station, and they are not under the threat, suddenly, their experiment will be canceled. The major difference between being in this field between Europe and the United States is the following. In Europe, once a satellite project is approved, it's normally carried to an end. In the United States, in accelerators and in space projects often, halfway through, they are canceled. The cancellation of SSC, of ISABELLE, which I mentioned, make the Europeans somewhat hesitant how to commit themselves to this.

Senator HUTCHISON. First of all, I so appreciate what you said about—rather than competing, that, really, America should be into collaboration. For one thing, because science budgets are limited, probably, everywhere, and we can do better if we cooperate, it is my view that America will stay on top. We are on top. We can stay on top if we collaborate. I think if we go down into the "we're only competitive" trenches, that we will start losing. And I appreciate the point that you made about that, and I think we have to be the leader, and act like the leader, and continue to move forward with collaboration. We will grow from that, as well as others growing with us. So, I appreciate that, and I think it is appropriate, as we talk about the Space Station and how we make sure that it is worthwhile.

Let me move to one other point, and then there are others here who want to speak, I'm sure.

Talking about the superconductors—superconducting super-collider, I thought it was the biggest mistake Congress ever made. I never, ever thought that Congress would really go through with something that had started and was actually halfway there. And I think it was—it wasn't even penny-wise, much less pound-foolish. But you had said that you think we could still build the next generation of accelerator if we make that commitment. But you've also said that we have more energy sources in space for that type of experiment than you could ever reproduce on the ground. So, could we use the International Space Station as our accelerator substitute, since we did lose the SSC, and can we have the same kinds of discoveries and information from that in lieu of going for the next accelerator?

Dr. TING. Senator, you ask a very penetrating question. In space, you produce the highest-energy accelerator, but the intensity is low. And so, you need a very large detector. On the ground, you can shoot an electron and a positron, and let them collide. You make more of a selection. And so, you do a different type of physics. The United States Department of Energy has an intensive study to do the next-generation linear collider. It's 100 miles long, electrons and positrons collide. And, because of this, I don't know how to say it, but it's almost the same as the Space Station. I think it is extremely important there is this type of collider. Now it is a huge international competition, whether it's to be in Japan, whether it's going to be in Geneva, whether it's going to be in Hamburg. And I think, for the United States, it is very important that it be located in United States.

Senator HUTCHISON. Mr. Chairman, could I just finish with one last question? And that is, what would be the timetable that we would have to set in place for America to compete for the next-generation of supercollider? And, also, when is it necessary to go beyond what is in Geneva?

Dr. TING. The one in Geneva will start operating in 2 years. And the next-generation collider, because of technology—you have to develop an enormous amount of new technology—would be on the only order of 10 years, I would think.

To address your first question, Senator, about the Space Station, nobody has measured accurately what is in space with charged particles, high-energy ones. And the Space Station will provide the first accurate measurement to probe what is out there. That is why it's so fascinating to so many Europeans and Asians working on this.

Even though the experiment I present to you, the cost is $1.2 billion, mostly coming from Europe, but because it's done on the Space Station, was clear view—be viewed as a American experiment.

Senator HUTCHISON. Thank you so much.

Thank you, Mr. Chairman.

The CHAIRMAN. Senator Smith?

STATEMENT OF HON. GORDON H. SMITH, U.S. SENATOR FROM OREGON

Senator SMITH. Thank you, Mr. Chairman. Thank you, gentlemen, for your contribution this morning.

A number of us were recently privileged to go to a dinner in which U.S. competitiveness in the world was the subject of table conversation. One of the points made to us is that our immigration laws, frankly, make it difficult to recruit the best and brightest from around the world, and then, at the conclusion of the education of those who do still make it through the maze of laws appropriate to our current law, are forced back home right away.

The suggestion was made to us that part of our outreach to the world ought to have a focus on science and math, where we are beginning to lag behind other countries, in terms of education and accomplishment. Is it your experience in academia, that if we change those laws to allow gifted people in science and math to come here, and then, instead of requiring their return, upon graduation, made a path to citizenship much more possible, even expedited, that that would help us to stem the current loss we are suffering in the scientific community?

Any of you can answer.

Dr. HEATH. America, in terms of science, is still the land of opportunity. It's still the only place where—I mean, one reason why we do OK, even though we have a terrible K through 12, is that, at any stage, someone can recover and decide they're going to become a scientist. And people from outside the country can come here and take an assistant-professor job, set up their own labs, at an age that is far younger than what happens in most Asian and European countries. And so, we have a very attractive palette that we can use to attract these folks.

What's—in fact, if you look at most of the technologies that are being developed now, I would argue that it's exactly those scientists that have come from overseas, and come here, and taken advantage of the opportunity that we have, that are making those things happen. And we're beginning to see that reverse, because it's harder for people to come in, it's harder for people to stay. But if you made it easier, we would——

Senator SMITH. Would——

Dr. HEATH.—the benefit would be tremendous.

Senator SMITH.—would holding out expedited citizenship be an extra attraction?

Dr. HEATH. Oh, absolutely.

Senator SMITH. Any of you have a comment?

Dr. AGRE. I'd just like to agree with Dr. Heath and expand a little bit. I think when excellent scientists trained in the United States do return to their countries, it's not always a loss. We have a U.S.-trained individual, we have a friend for the rest of the career of that individual, a friend of the United States in Japan, in China, in Germany. So, I think to have a revolving door would be good. And I think the biggest problem with the decline in the entry—of scientists now are the recent problems, after 9/11, where we had scientists who would come here to work, and then they'd have to go back to their countries and have a visa recertified and wait 2 months for an interview in a hotel in Tokyo or someplace.

So, I think it has been better in the past, but I think providing citizenship would be an excellent way of attracting wonderful people to the United States. And they're a very hardworking group.

Dr. CORNELL. I'd just like to echo that. I think that's a terrific idea.

Senator SMITH. And if we did that, in your experience, could you put a percentage on how many would stay, if they were permitted? Half of them? I mean, I——

Dr. AGRE. At least. At least.

Senator SMITH. I agree with the revolving door, but, on the other hand, if we're a melting pot—if we can make them Americans and they bring all the gray matter into our country, do we start reversing the curve and heading up again?

Dr. CORNELL. Yes, I'd say, again, half or more. I've seen trained—a German guy, citizenship didn't work out. It made me cry to think that he wanted to stay here. He would have been a boon to our economy. Just exactly the kind of person we'd like to have as future Americans.

Dr. HEATH. Just echoing that a little bit, I, myself, must get three or four postdoctoral applications a day from overseas. And so, we have a great filter. We can pick out the really singular people to come here. And if half of them stay, that's a big boon.

Senator SMITH. Well, Mr. Chairman, as our congressional focus turns to immigration in the new year, I really think this ought to be a component of the new immigration laws that this Committee ought to lead on, and insist upon being included, because I think it—you know, America has benefited from every race, every ethnicity from around the globe, and we have to leave that door open to the best and brightest from all over the world, for our future's sake.

Thank you.

The CHAIRMAN. I think our problem has to be to find a way so that we can attract the best and brightest—sorry about that.

I think what Dr. Ting is telling us is that we ought to find a way to attract the best and the brightest to our country, and to insist on it still being a United States experiment, and that's what it is, because Dr. Ting heads it. There is the basic problem of financing, which is one that I'm too familiar with, having spent more than 8 years as Chairman of the Appropriations Committee. The amount of funds available for discretionary spending is declining every year. And I don't know any way to make science an entitlement. You know, we have entitlements which automatically come out of the treasury, others that are discretionary money. The competition of that—those funds increases drastically each year.

But I, again, want to thank you very much. I, again, apologize for the timeframe. We thought this would be the nicest day, because we would be in a quiet session and have everybody just waiting for the continuing resolution to come over, and would be pleased to have a chance to listen to you gentlemen tell us about the role of your institutions and your background and meeting some of these basic problems we face. But I do intend to put your statements in the Congressional Record. And I also intend to ask you, Dr. Ting, if you'd give me a printout of that—I've never done it before, but I think I'll give your statement on the floor, in full.

I can't take these PowerPoints on the floor, but I can take printed charts to emphasize your points.

Dr. TING. It would be an honor for me to do so.

The CHAIRMAN. Very interesting.

And, Dr. Heath, Jim, I thank you very much for the suggestion that you could put together a group to come in and really give us some reason to be more interested in what you're doing. And I appreciate very much your effort.

And, Dr. Agre, Dr. Cornell, Dr. Ting, we're grateful to you for taking the time. We'll see what we can do to fund some initiatives that might bring you back to help support those initiatives. And I'll keep in touch with you about it.

STATEMENT OF HON. CONRAD BURNS, U.S. SENATOR FROM MONTANA

Senator BURNS. Can I ask a question?

The CHAIRMAN. You certainly may. I didn't know whether you just came to listen or talk.

Senator BURNS. Well, we all just get through life taking up space. I'm one of those.

The CHAIRMAN. Hit the button.

Senator BURNS. My button's already hit.

I chaired Science and Technology and NASA, on this Committee, and it was very enlightening to me of what's going on in our world. And when Senator Smith mentioned the attraction this country has to people who want to do research-and-development work, and also to come and to learn and then go back home, I go back a little bit on my background. I'm no tower of mental strength, I will tell you that. And my father was a small farmer in the State of Missouri. And he was born in 1906, died in 1992, at the age of 86. He was convinced that he had lived the greatest span of years of the planet. Even though he was a small farmer, he said, "We have gone from horseback to the moon in my span of years. And we had the technology, and we all got to watch it happen, the conclusion of when we walked on the moon." That's always had a lasting impression on me, as just how great a free society can be, when you allow the freedom to experiment, to probe the unknown, and the gain of knowledge.

We operate around here with a single-bitted ax, and whenever we let those who have great talent to do R&D here, and then force them to go home, we are only using one bit of the ax, but it cuts both ways. If they decide they want to go home and do their work, that's a wonderful thing; we have a friend there, and his work continues, and we continue to be a society that gains from that. If they choose to stay here and do their work, we are doubly blessed by this talent. And I am like Senator Smith, that we should look very seriously on how we look upon this community. When we start doing our work that goes way beyond—I know we were—the supercollider, I was here when that all started—Dr. Ting probably remembers that—and very supportive of the idea. And we had a place in Montana for you all to come and work, all set aside for that. When it didn't happen, I was very sad about that. I, like the Chairman here, appreciate your spending some time with this Committee—and I'm sorry I didn't make it up until just a little while ago, because I have a very deep interest in this, because I, more or less, deal with our research in how do we feed and clothe all the people that inhabit this Earth. And we, in America, we have a great ability to produce. And even when it filters down to my little Montana State University, where we do a lot of work in those lines, what you do gives us the platform of which we can really take that science, that work, and apply it to everyday life for all of us, and all of us gain from that work. And that's the way I make that link. I think Montana State probably ranks in the top schools of attraction of grants and money. We do, in R&D. And most of it has to do with how we feed and clothe ourselves, the production of food and fiber.

And so, I just want to thank you for coming up and sharing your thoughts with us. We need to do more of this. We don't do enough on the street, so to speak, but I'm kind of an on-the-street kind of a guy. I started out in a cow camp a long time ago, making $135 a month and sleeping on the ground. We gathered cattle late one year, and it snowed on us, and you roll out in the morning, out of that bedroll, and shake the snow off and put that old hat back on, climb back in the saddle for another day's ride. And all at once that romance of cowboy left me.

[Laughter.]

Senator BURNS. And so, I just want to express my appreciation here this morning, for sharing your thoughts and the material that you leave behind. And I thank you for your work, because you've given us a real platform, a real launching pad, of which we take what you do and apply it to the benefit of everybody who lives on the planet.

Thank you very much. And thank you.

The CHAIRMAN. Thank you all very much. We have a vote going on right now, so we're going to have to recess. And I had hoped that other Senators might come before we're through, but, with this vote—the start of a vote, that will not be the case.

I do want to make a personal invitation to you, when we're off the record here. But I—again, I do thank you, again, for coming and for your testimony. All of your statements will be printed in the record in full. And I look forward to getting a copy from Dr. Ting.

Thank you all very much.

[Whereupon, at 11:35 a.m., the hearing was adjourned.]

A P P E N D I X

PREPARED STATEMENT OF HON. DANIEL K. INOUYE, U.S. SENATOR FROM HAWAII

Mr. Chairman, I want to begin by wishing you a happy birthday. We've known each other for many years and I am happy to say that you're looking better than ever.

I also want to thank you for calling this hearing. You have brought together a remarkable panel of scientists.

Science is an important subject. The pursuit of science and expanding the boundaries of human knowledge is a hallmark of mankind.

Science is the basis of technological innovation and technological innovation is a primary driver of economic growth and prosperity. In turn, if we are successful, our quality of life improves.

Today, we are facing a real problem and one that will affect the future of this country. Right now, the United States is not graduating as many scientists and engineers as other countries around the world.

Our Committee jurisdiction ranges from the bottom of the ocean to distant galaxies. Science plays a role in almost everything we deal with—whether it is the safety of a plane or car, our energy sources, the need to make advancements in security or how we reach the stars.

But we also have a responsibility to the next generation. We need to find a way to inspire our young people and get them engaged in science and math. We need to increase the number of science and engineering graduates so that this country can continue to come up with next great idea, develop the next great product, and discover the next great medicine that will save lives. Every bill that this Committee writes should have this objective in mind.

This country has a long history of producing great things, all of which were based on a strong commitment to funding basic research. The Army funded the discovery of the transistor. The Internet was invented by the Department of Defense. Research funded by the National Institutes of Health is producing life-saving drugs.

But over the past few years, this commitment to science has faltered. Although Congress supported doubling of funds for the National Science Foundation, this investment has not materialized. We need to reaffirm this commitment and ensure that scientific research in the United States gets back on track.

Today, we have convened a panel of experts to share their views and visions for the future of science in our country. We need to learn from you and get your input on how best to reinvigorate our national commitment to science.

Mr. Chairman, again, happy birthday. We will both learn from our experts today a great deal that we can pass on to future generations through our legislative efforts.

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