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2006 NOBEL LAUREATES

HEARING

BEFORE THE

SUBCOMMITTEE ON SCIENCE, TECHNOLOGY, AND INNOVATION

OF THE

COMMITTEE ON COMMERCE, SCIENCE, AND TRANSPORTATION
UNITED STATES SENATE

ONE HUNDRED TENTH CONGRESS

FIRST SESSION

MAY 2, 2007

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ONE HUNDRED TENTH CONGRESS

FIRST SESSION

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2006 NOBEL LAUREATES

WEDNESDAY, MAY 2, 2007

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

The Subcommittee met, pursuant to notice, at 4:02 p.m. in room SR–253, Russell Senate Office Building, Hon. Mark Pryor, presiding.

OPENING STATEMENT OF HON. MARK PRYOR, U.S. SENATOR FROM ARKANSAS

Senator PRYOR. The Committee will come to order, and we will have probably at least one or two more Senators come and go. We have a very busy Committee schedule today on the Senate side. But, on behalf of Chairman Inouye and Vice Chairman Stevens and Senators Kerry, Ensign, and Boxer, and the Science, Technology, and Innovation Subcommittee, I would like to welcome our distinguished guests and the 2006 Nobel Laureates in Chemistry, Medicine, and Physics.

Taken together, these gentlemen represent the first American sweep of the science Nobel Prize categories since 1983. Their achievement will, I hope, inspire young people to study science and inspire policymakers to rededicate themselves to preserving America's role as the world's preeminent scientific nation.

For the past half-century, the United States' investment in basic research has been the engine that drives our economy. In 1945, Vannevar Bush submitted his report, "Science: The Endless Frontier," to President Franklin Delano Roosevelt that spurred the creation of a system of public support for university research that endures to this day.

The goal of basic research is to discover new scientific ideas, principles, and theories. Nobody can predict the next breakthrough in science; however, the connection between basic research and the economy is straightforward. Basic research produces the discoveries that, through innovation, become the products that transform and strengthen our economy.

The American Association for the Advancement of Science reports that the overall Federal investment in research and development would increase to $143 billion in Fiscal Year 2008. However, in a repeat of past budgets, the continuing administration priorities of weapons and space vehicles development would take up the entire increase, and more. Funding for the basic and applied research portion of the R&D portfolio would actually fall by 2.1 percent, to $55.5 billion.

As a percentage of GDP, the U.S. Federal investment in physical sciences and engineering research has dropped by half since 1970. Gains by NSF, NIST, and the DOE Office of Science would be more than offset by cuts in other research agencies, such as the National Institutes of Health. These investments, while welcome, overall, raise the question of whether the United States will continue to make the sufficiently balanced investment necessary to maintain its own capacity for scientific discovery and technological innovation and remain a leading player in an increasingly competitive global marketplace.

Last week, the U.S. Senate passed S. 761, the America COMPETES Act. This bill is based heavily on the recommendations of the National Academies' report, "Rising Above the Gathering Storm." I'm proud to be a cosponsor of the legislation. The America COMPETES Act calls for a doubling of the basic research budgets of the National Science Foundation, National Institute of Standards and Technology, and Department of Energy Office of Science. I hope that this legislation will begin to restore our science research infrastructure and competitive edge.

I look forward to working with Chairman Inouye and Vice Chairman Stevens, to incorporate the recommendations that we hear today as we move forward on the bill.

Now, I would like to turn the program over to the Vice Chair, Senator Stevens of Alaska, and let him make some opening statements.

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

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

I've been honored to be with these gentlemen earlier today. I will put my statement in the record and will look forward to hearing from them here again.

[The prepared statement of Senator Stevens follows:]

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

Mr. Chairman, thank you for holding this hearing today. It is quite a privilege to be able to hear from some of the brightest scientific minds in the world.

It has been more than 20 years since Americans have won Nobel Prizes for medicine, chemistry, and physics all in the same year. I would like to congratulate all of the witnesses for their remarkable achievements. From the microscopic to the astronomical, the research conducted by these individuals is remarkable and will further advance the knowledge of our world for years to come.

Groundbreaking basic research is the cornerstone of technology and societal progress. This type of research helps to improve the health of our people, stimulate our economy, preserve our environment, and strengthen the national defense over the long-term.

The continued funding of basic research is critical to maintaining the United States' competitive edge in the world. By focusing our efforts to support basic research through the National Science Foundation, the National Institute of Standards and Technology, and the National Labs, we are investing in more bright minds and new ideas that will help to ensure that future innovations that transform the world will originate here in the United States. By supporting and improving the teaching of science, technology, engineering, and mathematics, we are also encouraging the next generation of American students to follow the example of today's Nobel Laureates.

Last Wednesday, with the passage of the bipartisan America COMPETES Act, the Senate sent a clear message that our Nation's competitiveness is a major priority that must be addressed as soon as possible. I was pleased to play a major role in developing this legislation to increase funding for basic research, strengthen science, technology, engineering, and math education, and develop a 21st century innovation infrastructure. I hope that we will be able to get this bill signed into law as soon as possible.

Once again, I look forward to hearing from all of our witnesses today.

Thank you.

Senator PRYOR. Thank you. Well, you said you were going to be brief. And that's right, isn't it?

I'd like to introduce two of our Nobel Laureates, and then Senator Boxer will introduce the three Nobel Laureates from California.

Let's see, Dr. Craig Mello holds the Blais University Chair in Molecular Medicine at the University of Massachusetts Medical School. He was awarded the Nobel Prize in Medicine for his work on RNA interference.

Dr. John Mather is the Chief Scientist at NASA, and is the co-recipient of the Nobel Prize in Physics. Dr. Mather was instrumental in the development of the Cosmic Background Explorer that measured the residual heat radiation from the Big Bang.

We'd also like to recognize Dr. Jack Wilson, the President of the University of Massachusetts, who's in attendance today.

Senator Boxer?

STATEMENT OF HON. BARBARA BOXER, U.S. SENATOR FROM CALIFORNIA

Senator BOXER. Thank you so much, Mr. Chairman.

Let me apologize in advance to you, Senator Stevens, and our witnesses, because I have other Committee work, but I just had to come over here to introduce to the Committee three of the finest minds, I'm sure, out of the five that are all the finest minds in the world. My three, George Smoot, Roger Kornberg, and Andrew Fire, all are Californians, and all are 2006 Nobel Prize winners. I take great pride in the fact, and I know Senator Feinstein does as well, that these three Californians were among the five Americans who swept the Nobel Prize science awards last year, as our Chairman has said, something that hasn't happened in more than 20 years.

I will start with Dr. Smoot, who shared the Nobel Prize in Physics. He's been a professor at the University of California at Berkeley, in the Lawrence Berkeley National Lab, since 1970. In the years since, he and his team have been dedicated to understanding the origin of galaxies and stars, and to getting a glimpse of what the universe looked like in its infancy, when it was only about 300,000 to 400,000 years old. Dr. Smoot told my staff that he had so many questions when he looked up into the night sky as a young boy. It's such a joy to see that he's continued searching for the answers, and, in turn, he has taught us all so much.

Roger Kornberg, winner of the Nobel Prize for Chemistry, has been Winzer Professor in Medicine and Structural Biology at Stanford since 1978. While Dr. Smoot looked to the sky and asked questions, Professor Kornberg looked down into a microscope to explore the building blocks of life. He has worked over the years to discover and describe the process of how genetic information is copied from

DNA inside a cell's nucleus and then transferred out to the rest of the cell so that proteins can construct the organism and allow it to function. Working with his team, he developed highly detailed pictures that describe this copying process known as transcription, and the applications of this work have fundamental medical importance.

Andrew Fire, who shared the Nobel Prize in Physiology, or Medicine, is Professor of Pathology and Genetics at Stanford, where he's been since 2003. Professor Fire and his colleague Craig Mello, of the University of Massachusetts Medical School, led a team that discovered certain molecules, as my Chairman has explained, that discovered that certain molecules can be used to turn off specific genes in animal cells. And this marked the first time biologists were able to selectively silence the voice of one gene among the tens of thousands that give a cell its instructions from development to death.

Like Dr. Kornberg's discoveries regarding the transfer of genetic information from DNA to the rest of the cell, Dr. Fire's work has tremendous medical implications, because treatments based on the ability to ID and silence a gene are being tested in many animal models of disease—high cholesterol, HIV, cancer, and hepatitis, among others—and clinical trials have been launched.

Mr. Chairman, these giants of science are here today to talk about the importance of basic science research. The great discoveries of tomorrow come when the greatest minds are given the resources to do their work. And I know we all want to help them get those resources.

So, I want to thank you for this hearing and for the opportunity you've given me to introduce these great Californians, and to meet them all.

Senator PRYOR. Thank you. Senator Boxer, thank you. And we understand that you're going in different directions today, so——

Senator BOXER. I'll be here for a while.

Senator PRYOR. Thank you for being here. And I know that the panel appreciates it, as well.

Gentlemen, your accomplishments are great, and we are very honored to have you here today in the United States Senate. And I understand that there's a speaking order, but I guess the group has talked and decided that you don't really need to make opening statements. Is that right? So, why don't we do this, why don't we just go down the row, if that's OK, and just let you introduce yourselves, say a couple of sentences, and then we'll start our questions and answers. How does that sound?

Would you like to start?

STATEMENT OF DR. ROGER KORNBERG, WINZER PROFESSOR IN MEDICINE, STANFORD UNIVERSITY

Dr. KORNBERG. So, I'm Roger Kornberg——

Senator PRYOR. And, I'm sorry, there's a microphone there. Just make sure it's on.

Dr. KORNBERG. Oh, now it's on. Can I be heard?

I'm Roger Kornberg, from Stanford University, and I understand that we won't make the statement that we prepared, so I'll confine most of my remarks to the discussion that follows.

I did, however, want to comment on one aspect, in case it doesn't arise, and which I think is of critical importance, and it is that all of our work over the years was supported by NIH. The cost was about $20 million over 30 years, mostly used for the stipends of more than 80 graduate and postdoctoral students. Due to current constraints on the NIH budget, I can tell you that virtually none of the work we did then would be supported today. I can tell you that a finding I made in 1974, of great importance, of a fundamental particle of the chromosome would certainly not be successful in the competition for a research grant. And the reason is, I had no idea at the outset what I might find, and I had no idea how to go about it. I only knew that the problem was important and could try and advance reasons why I should be given the opportunity of doing so.

In a similar way, the work on RNA polymerase structure, for which the Prize was given, was only supported by NIH after it became clear the work would succeed. When we began, the prospects for success were virtually nil. There was no way of producing the RNA polymerase molecule. There was no hope of forming the crystals that were needed to obtain the images that we eventually obtained. And there was also no technology at the time for deriving an image.

Coming to the point that I wished to make in these remarks, the reason for the disconnect between funding and discovery is clear, and Senator Pryor has already commented upon it, and it is that discoveries are, by their nature, unanticipated, they're completely unknown beforehand, they can't be sought out in a deliberate way, they can't be proposed to a funding agency or evaluated by review groups.

So, how, then, are discoveries made in our American system? And the answer to that question is: by risk-taking. Scientists supported to do straightforward research divert some of their funds for testing new ideas. If they succeed the results form the basis of a successful grant application. If they fail, they may be in serious trouble, and be unable to continue, even with their original research.

Now, the risky nature of truly innovative research is the strength, and also the weakness, of our system. In the past, when NIH funded some 20 to 30 percent of new grant applications, most able people could get a grant, and then they would conceive of ideas that they would try on the side in the manner that I've mentioned. Occasionally, an important discovery was made, and this is the way innovation happened. Today, with funding levels at 10 percent or less, many fine investigators have lost support; few, if any, will take risks; and already the pace of discovery is falling dramatically.

In the March 23, 2007, issue of *Science* magazine, Senator Arlen Specter is quoted as asking the reasonable question, "What's going to happen to NIH if the budget is cut by $500 million," a cut of about 5 percent on the funding for basic research in the biomedical sphere? And the answer is, of course, that the amount of research done, measured, for example, by the number of publications, is going to fall by about 5 percent. But innovation will be stifled. It will be eliminated almost entirely. The chilling effect of funding cuts ripples through our system. It deters bold action and creativity on the part of established investigators. It discourages young scientists even from entering the system. This has already happened. My European colleagues told me, recently, they've been keenly aware of a reverse brain-drain that is already underway.

The last point that I'd like to make is to reiterate what I have just said, and it relates to the adverse effects of flat funding or even failing to keep pace with inflation at the NIH, where, in fact, a substantial increase is desperately needed.

The worst adverse effect is the disillusionment of young people. The choice of a career in science represents an enormous sacrifice. A passion for science must be weighed against a long period of training, 10 or more years of postgraduate study at low wages, and then the possibility of no career at all when you're done. The importance of young scientists can't be overstated. Progress in science and discovery, in particular—is the work of the best and youngest minds. America has taken pride in the Nobel Class of 2006 that is with you here today. If we don't take action now to restore enthusiasm among young people for the pursuit of science, there will be no American Class of 2026.

I thank you.

[The prepared statement of Dr. Kornberg follows:]

PREPARED STATEMENT OF DR. ROGER KORNBERG, WINZER PROFESSOR IN MEDICINE, STANFORD UNIVERSITY

Chairman Kerry, Ranking Member Ensign, and Members of the Subcommittee, I am grateful for this opportunity to describe our research to those who support it. I will give a brief account of the research, its significance, and future prospects. Then I wish to explain some of the challenges we face and how they may be overcome.

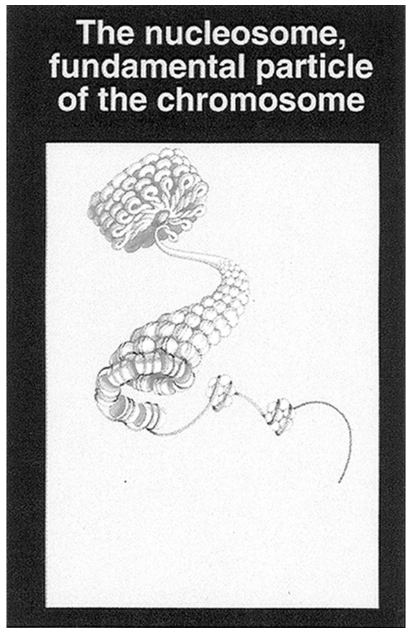
The Control of Gene Expression

Our research has to do with genes, which direct the formation and the activities of our bodies. Every cell in our bodies contains a complete set of genes. Which subset of genes is used in a particular cell determines whether it becomes nerve, muscle, blood, liver and so forth. The goal of our research and that of many others has been to understand how this controlled use of genetic information is accomplished. The practical implications are enormous. All infectious disease entails genetic control. Cancer results from a breakdown of control. Therapeutic approaches such as stem cells require intervention in genetic control.

Genetic information has been likened to a blueprint or a book. In order to use the information, the book must be opened and read. Our work has uncovered principles of both the opening and the reading of genetic information. We are now close to understanding genetic control.

The Nucleosome, Fundamental Particle of the Chromosome

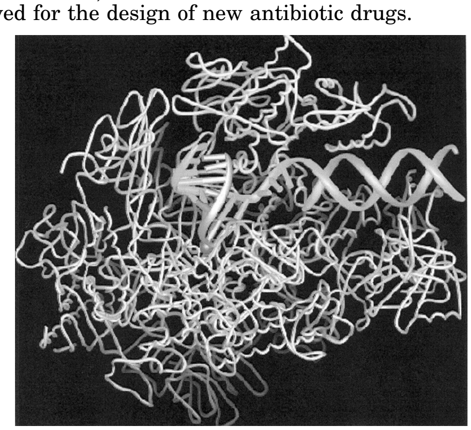
Genetic information is contained in a long thin molecule of DNA. Human DNA is a meter in length and must be compressed to a micrometer in our cells. This might be accomplished in an organized way by spooling, as is done for sewing thread or garden hose. The problem is that to gain access to a gene in the middle, the entire length must be unspooled. Nature has solved this problem by the use of mini-spools. I proposed in 1974, and it has since been verified, that DNA is wrapped around a set of eight protein molecules in a particle known as the nucleosome. A million of these particles are strung together in a human chromosome. For access to a gene in the middle, only a few particles need be unspooled, while the rest are left undisturbed. Unspooling is a key control point for gene activity, and is already a promising target of anticancer drugs.



RNA Polymerase, the Gene-Reader in Our Cells

Once DNA is unspooled, the genetic information can be read. The gene reader is a protein machine known as RNA polymerase, which copies the genetic message into a related form called RNA, in a process known as transcription. RNA directs the synthesis of proteins, which perform all bodily functions.

In work done over the past 25 years, we have obtained a picture of RNA polymerase in the act of transcription. RNA polymerase is composed of 30,000 carbon, oxygen, and nitrogen atoms. Our picture shows the precise location of every atom. In this picture, we see the DNA double helix entering the polymerase machine and the RNA product as it is formed and released. This picture has revealed the basis for readout of the genetic code, and how occasional mistakes are corrected. It has already been employed for the design of new antibiotic drugs.



Structure of RNA polymerase in the act of gene transcription. Chains of protein building blocks are shown in white and orange. Gene DNA, in the form of a blue and green double helix, enters from the right. RNA, shown in red intertwined with one DNA strand, exits from the top.

The Future: A Molecular Computer for the Control of Gene Expression

RNA polymerase does not act alone in the readout of genetic information. An additional 50 protein molecules participate directly in transcription. We discovered, in particular, a giant assembly of 20 proteins called Mediator that serves as a kind of molecular computer. Mediator receives information from inside the cell and from the environment, which it processes and delivers to RNA polymerase. A major objective for the next decade of our work is to determine the atomic structure of Mediator and to understand the control of transcription. We already know that mutations in genes encoding Mediator can cause cancer. Knowledge of Mediator structure will enable us to correct many such problems and to intervene more generally in the control of gene expression.

The Challenge of Funding Basic Research

Our work has been supported almost entirely by the NIH. The cost was about $20 million over 30 years, mostly for the stipends of the more than 80 graduate and postdoctoral trainees involved. Due to current constraints on the NIH budget, virtually none of our work would be funded today. I can say with certainty that *a grant application for the research leading to the discovery of the nucleosome, fundamental particle of the chromosome, would not be approved.* The reason is simple: I had no idea at the outset of what I might find, and no good idea of how to go about it. Our *RNA polymerase structure work was supported by NIH only after it became clear it would succeed.* When we began, the prospects for success were virtually nil—no way of producing the RNA polymerase, no hope of forming the crystals needed for imaging, and no technology for deriving the image.

The reason for the disconnect between funding and discovery is clear: funds are awarded for compelling ideas, supported by preliminary evidence, creating a high likelihood of success. But *discoveries are by their nature unanticipated, completely unknown.* They cannot be sought out in a deliberate manner. They cannot be proposed to granting agencies or evaluated by review groups. So how are discoveries made in the American system? The answer is by risk-taking. Scientists supported to do straightforward research may divert some of their funds for testing new ideas. If they succeed, then the results form the basis for new grant applications. If they fail, they may be in trouble and be unable to continue even with their original research.

The risky nature of truly innovative research is both the strength and the Achilles heel of our system. In the past, when NIH funded approximately 20 percent of new grant applications, most capable investigators could obtain support, some of them would conceive of and try new ideas, and occasionally an important discovery was made. Today, with funding levels at 10 percent or less, many fine investigators have lost their support, few will take risks, and the pace of discovery will fall dramatically.

In the March 23, 2007 issue of *Science* magazine, Senator Arlen Specter is quoted as asking the reasonable question "What's going to happen to NIH if the budget is cut by $500 million?" The answer is that the number of publications from NIH-sponsored research will decline accordingly, by about 5 percent, but innovation will be stifled across the board. The chilling effect of funding cuts ripples through the system, deterring bold action and creativity on the part of established investigators, and discouraging young scientists from entering the system. This has already happened. My European colleagues have noted a reverse brain drain already occurring now.

There is another way in which small budget cuts can have a disproportionate effect. Research is highly synergistic. One part depends on others. For example, my own determination of the RNA polymerase structure was critically dependent on the work of hundreds of physicists and engineers, on synchrotrons such as that at the Stanford Linear Accelerator and on cutting-edge photon physics.

Of all the adverse effects of flat-funding or even cutting the NIH budget, the disillusionment of young people is the worst. The choice of a career in science already represents a great sacrifice. A passion for science must be weighed against a long period of training—10 or more years of postgraduate study at low wages—and the possibility of no career at the end. The importance of young scientists cannot be overstated. To paraphrase an illustrious politician, it's the people, stupid! Progress in science, and discovery in particular, is the work of the best young minds. America has taken pride in the Nobel class of 2006, present here today. If we do not take action now to restore enthusiasm for the pursuit of science, there will be no American class of 2026.

Discovery as a Driving Force of Progress

Much has been said about the value of basic research, and I am sure the arguments are well known to you. I would like to add some points not so often stated. Scientific medicine is comparatively new, just over a hundred years old. The advances already made have impacted the lives of us all. Every major advance can be traced to a discovery made in the pursuit of basic knowledge, not for a medical or economic purpose. Some examples are X-rays, antibiotics, magnetic resonance imaging, recombinant DNA, and structure-based drug design. Future advances, including the prevention or cure of cancer, AIDS, Alzheimer's, and other dread afflictions, will come from new discoveries and new information. Efforts currently targeted toward these and other worthy ends are unlikely to succeed. I recall the words of Lyndon Johnson to the effect of "life-saving discoveries locked up in the laboratory." This serious sentiment was mistaken. Application of existing knowledge is not the limiting factor. The knowledge itself is limiting.

It has been remarked that we know 1 percent of everything about the human body. A small fraction of a percent would probably be more accurate. But consider how enormous have been the benefits to our health and our economy from what little we know now. Imagine how great would be the benefits of knowing the remaining 99 percent!

There is a further overarching purpose to basic research. An urge to explore is a part of our nature. It was a major factor in the evolution of our species. It has motivated us to go to the Moon and to outer space. The exploration of inner, human space is no less grand. It is also an expression of the human spirit.

Senator PRYOR. Thank you. And, by the way, all of your—the text of your statements will be made part of the record, so we'll—you can submit those for the record.

Next?

STATEMENT OF ANDREW FIRE, PH.D., PROFESSOR OF PATHOLOGY AND GENETICS, STANFORD UNIVERSITY SCHOOL OF MEDICINE

Dr. FIRE. Maybe I should just make a couple of comments about the value of today's hearing. I think one of the things that's important to communicate is the enthusiasm that we've seen today in the Senate and the House for science, as an enterprise and science as an exploration. That's something that young people and young scientists in particular really need to hear: the extent to which their work is valued by the society as a whole; if they're thinking about a career, the extent to which their ideas are needed by those of us already in science (particularly as some of us are getting a little bit long in the tooth). I hope today's hearing will help to send these messages.

[The prepared statement of Dr. Fire follows:]

PREPARED STATEMENT OF ANDREW FIRE, PH.D., PROFESSOR OF PATHOLOGY AND GENETICS, STANFORD UNIVERSITY SCHOOL OF MEDICINE

Senator Inouye, Members of the Committee, ladies and gentlemen. Thank you for the invitation today to speak on science and its value to our society. This is a certainly a worthy topic for discussion in such a forum and I hope that my comments will be helpful in stirring up debate and discussion.

Before we consider the value of science, we should first consider the goals of the scientific enterprise in this country.

Although each individual scientist brings a unique set of goals to their work, certain themes run throughout the scientific community and elsewhere:

- Every American and every citizen of the world should have the opportunity to live a full and complete life without the ravages of tragic disease.
- Every American and every citizen of the world should have access to sufficient resources and energy to fulfill their potential as individuals and as members of society.

- Every American and every citizen of the world should have the opportunity to live in a world where they are safe from threats of terrorism, war, and other violence.
- Our children, our grandchildren, and generations to come should have opportunities that are comparable to the best that our current society has to offer.

Scientific progress is by no means the only component in pursuing these goals. It is nonetheless a critical part. As our world inevitably changes, we will need to understand how these changes can affect our lives. As we become capable of greater manipulation of our environment, so questions of appropriate behavior, balance and sustainability become critical. We are at a turning point where technology and science will underlie most of the major decisions made by individuals, groups, and societies. There is no turning back from this.

Before we can talk about the value of science, we need to talk about limitations.

- Science can help us to learn how the world works. Science can inform our decisions by allowing us to predict, albeit imperfectly, the concrete consequences of proposed action. Science and technology allow us to manipulate the world within us and around us using an ever-expanding array of tools.
- Science can't, shouldn't, and doesn't supplant our value systems. The value we place on human life is not a scientific calculation. Likewise, the many issues we debate as a society: our allocation of resources between the young and the old, our definitions of the beginning and end of life, our ways to prioritize the individual and the society, our allocation of effort toward long term maintenance of the human race; all of these rely on fundamental value systems outside of and beyond the scientific enterprise. Although scientific data (from molecular biology to theoretical physics to economics) can in some case inform ongoing debates as to the material consequences of each choice, the eventual decisions must come from our values and value systems.

Before we can talk about the value of science, we need to talk about opportunities. From a portfolio too large to summarize, here are a few.

- A dedicated war on cancer has been a flagship of the American scientific enterprise for the last 36 years. Inroads toward improving treatment of many types of cancer have been made in this interval, often based on a pipeline model that starts from investigation of fundamental biology and continues through careful clinical trials. The pipeline is by no means swift, but the initial results have made a difference between life and death, and between hope and despair, for millions on young and old people. Despite these advances, cancer still takes a devastating toll on individuals and families alike. We know that we can do more.
- Infectious disease was declared to be a "closed book" in the 1960s, leading to a shift away from the commitment of this country to our public health agencies. This turned out to be tragically misguided. We now understand that new epidemics of infectious diseases are an intrinsic aspect of the dynamically connected society we live in: Flu, AIDS, SARS, Tuberculosis, Malaria and many more that we can only speculate on. Our capabilities for rapidly identifying and tracking infectious disease have never been better. Still, I am scared for the future. We know that we can do more.
- Clean, safe, and renewable, energy production may become the most pressing economic, scientific, technical, and political challenges of the 21st century. Science has provided an armful of possible contributions in the form of new sources and dramatically improved efficiencies. Despite the recent burgeoning of a new energy industry, an upcoming global crisis in energy availability and in the consequences of our current use patterns seem virtually certain. We know that we can do more.

Before we can talk about the value of science, we need to talk about some of the challenges.

- We do not train enough scientists, engineers, or doctors. We do not train enough teachers. To maintain a technologically driven society and to meet the challenges ahead, we need to vastly increase the number of technically trained individuals ready to work in all areas. Our needs in the area of science education are evident at all levels: in elementary, middle, and high schools, in college, graduate, and professional schools, in continued training of our scientific workforce, and in the sophisticated scientific training that the general public will need to make rational decisions. In none of these areas are we completely lost. Education in this country has a remarkable history. Many of our institutions are unparalleled in their quality anywhere in the world. At the same time, many of our young people never get the chance to make contributions that could uniquely benefit the society because their communities lack the needed educational opportunities. This is not an area that we can afford to ignore. Investment in education is an investment in our future. A neglect of this opportunity at any level would be a colossal mistake.

- The critical early discovery stages of the developmental "pipeline" for science and technology often take place, by nature and by necessity, in universities and non-profit research centers. Research of value in such open environments has only been possible with public support of Federal agencies. This research has driven both innovation and discovery in American science to an extent that the scientific enterprise in the U.S. is truly and uniquely a societal effort. In this realm we face a continuous challenge in maintaining a productive and creative scientific enterprise under the inevitably fluctuating conditions of public support. Science in the U.S. has thrived on a competitive granting system, a sink-or-swim arrangement that does a remarkable job in funding the most important and highest quality research while driving the establishment as a whole toward excellence. But how do we handle the inevitable instability in supply and demand, in the cost of research, in the size of the academic workforce, and in policies and outlook of the institutions of higher learning that are partners with the government in making this work? In times of expansion, there is ample room in the system for all types of ideas, all points within the pipeline, and all levels of venture-risk. In times of contraction, we all fear that the next grant review might end our research careers. Clearly, the solution here cannot be an infinite and exponential growth of the public research enterprise. Private support for science can smooth out some of the rough spots, but as a small fraction of the total there is simply not enough private support for more than a token level of stabilization. To allow some stability, interactions between research institutions and Federal funding agencies are crucial: many grantee institutions are finding that their role must now include a clear commitment to bridging support for their faculty, employees, and for ongoing scientific projects, even as they recognize that moving forward will only happen with Federal support. More institutions will realize this over the next few years. At the same time, the great value of continuity in our public investment in science and technology needs to be communicated. We are at a crossroads in this area in the biomedical community with many critical research programs that may not survive the next few years, many creative senior investigators shutting their labs, and many potentially brilliant young investigators afraid to choose careers in a field this unstable.
- Discovery-based investigations in academia make up just one segment of the larger scientific enterprise. Even the most important of basic discoveries make their impact through a development process that involves extensive further research in academic settings combined with research and development in the commercial sector. Translation of basic discoveries toward beneficial results relies on additional groups of dedicated and highly trained scientists, physicians, engineers, and others. Fulfillment of the potential from academic discoveries also requires massive investment in the commercial sector, considerable risk-taking, and a real chance that any given project will fail. In the biomedical area, we simply do not know enough about the individual human body or about the diversity in our species to predict the outcome for a proposed new treatment. Clinical trials must be done, they must be done carefully and safely, they are extremely costly, and a fraction give a disappointing result. Given the costs of clinical trials, the vast majority must be carried out in the private sector. When there is success, we have great advances in medicine. Although we also learn from the failures, this is rarely a consolation to the affected shareholders. For commercial translation of scientific discovery to continue there needs to be a reasonable expectation of possible return on investment. Much of this relies on the U.S. Patent system, itself a gigantic and often cumbersome endeavor that like so many of our institutions is both imperfect and the best we have. The patent system doesn't operate in an economic vacuum. For commercialization to benefit society there also needs to be a mechanism where technologies are available at prices that allow accessibility by all Americans who are in need. One of the lessons we may hope to learn over the next few years is how best to incentivize the risk-taking that is essential in commercial technology development while providing new technologies affordably to all who are in need.
- As basic and applied scientists in education, academics, government, and industry we can make the greatest positive impact by supporting each others endeav-

ors, training each other in the areas that we know best, and by listening to each other to understand the needs and potential of fields that are unfamiliar.

Before we can talk about the value of science, we need perhaps most urgently to talk about our own responsibilities as scientists.

- It is our responsibility to continue a scientific enterprise directed toward improvements for all Americans and for all people everywhere.
- It is our responsibility to seek out and pursue areas of inquiry where scientific progress could benefit humanity, whether it benefits a few individuals, a few communities, countries, continents, or the entire human race.
- It is our responsibility at each stage of scientific inquiry to integrate our work into the larger scientific community both in the U.S. and worldwide.
- It is our responsibility to carry out our research in an ethical, truthful, and open manner and to follow the rules and restrictions set down by our governments and our conscience.
- It is our responsibility to maintain a pride in the creativity and uniqueness of our own thought and research, while acknowledging and fostering the ideas and contributions of others.
- It is our responsibility as scientists to be leaders in teaching science at all levels.
- It is our responsibility to communicate the scope of scientific opportunities and the spectrum of progress to our leadership, to the public, and to our neighbors around the world. At the same time, it is an equal responsibility to communicate the limitations of our work, the challenges that we face in improving the human condition and the risks that come from increased ability to manipulate our bodies and our environment.
- The 21st century will bring new challenges, new opportunities, new risks, new technologies, and new understanding. It is our responsibility as scientists to make these work to the benefit of our society and of all humankind.

We will do our best.
Thank you Mr. Chairman.

Senator PRYOR. Thank you.
Dr. Mello?

STATEMENT OF CRAIG C. MELLO, PH.D., HOWARD HUGHES MEDICAL INSTITUTE INVESTIGATOR AND THE BLAIS UNIVERSITY CHAIR IN MOLECULAR MEDICINE, UNIVERSITY OF MASSACHUSETTS MEDICAL SCHOOL

Dr. MELLO. Thank you. Senator, it's an honor to be here. And I would like to just make a few brief comments.

I think we live in, you know, uncertain times, and we have, on the other hand, great opportunities. And those are the two reasons why we need to continue to invest in science broadly in this country.

Why do you make investments? Well, you invest for uncertain futures, for possible, you know, hard times ahead. You also invest when you see an opportunity and you don't want to miss it. You realize that there's a—some great new discovery that's been made, and now it's time to capitalize on that. That's the time we live in right now. We have both of those things going on.

We are capable now of tremendous advances in medicine. We have the blueprint for the human. We understand now the—every single gene that makes a human. And we have technology and approaches like RNA interference that allow us to inactivate those genes and examine the consequences and study outcomes, and even to intervene in diseases at the very basic level of—the genetic level of disease. This is exciting and breathtaking opportunity.

And so, just at the—just at the moment when we have this opportunity, what are we seeing? We've invested in the genome sequence. That genome sequence is up on the computers in China and every other country. What are we doing? Well, we're not investing—we're not investing in that opportunity.

So, I think, in the life sciences and medicine we really have to take another look at what we're doing, because these are the sources that will generate wealth and generate new innovative companies, the basis—for example, RNAi is already a multibillion-dollar industry in this country. These are opportunities that are being lost at this moment. So, I hope that we can bring that out further in further discussion.

Thank you.

[The prepared statement of Dr. Mello follows:]

PREPARED STATEMENT OF CRAIG C. MELLO, PH.D., HOWARD HUGHES MEDICAL INSTITUTE INVESTIGATOR AND THE BLAIS UNIVERSITY CHAIR IN MOLECULAR MEDICINE, UNIVERSITY OF MASSACHUSETTS MEDICAL SCHOOL

Good afternoon. Mr. Chairman and Members of the Committee, it is a privilege to have the opportunity to testify before you this afternoon.

In a small lab at the University of Massachusetts Medical School and a small lab at the Carnegie Institution of Washington, with support from the NIH and other private sources, Andy Fire and I made a series of observations that have sparked a revolution in our understanding of how the genetic information that makes us human is stored and expressed inside our cells. Today, as we speak, thousands of scientists in labs all over the world are building on these discoveries to understand and to develop treatments for human disease, to shed further light on the basic functioning of cells, and to study and modify plants, animals and microbes important in agriculture, biofuels and other applications essential to meeting the many needs of our civilization.

Mr. Chairman, members of the Committee, we as a nation, indeed we humans as a species, are dangerously out of equilibrium with our environment. Pressures from over-population and lack of quality medical care in third-world countries (and even here in the U.S.) are leading to millions of unnecessary deaths each year, deaths from diseases we know how to treat, and these medically-underserved populations are incubating new, potentially devastating pathogens. Alternative fuels and better crops must be developed to support populations that have already reached sizes that challenge the very productive capacity of the planet. In short, we need a call to arms, a call to fund science broadly in this country so that our Nation can face these challenges and can continue to lead the world toward a brighter future.

The discovery of gene silencing by double-stranded RNA—"RNA interference," or "RNAi," for which Andy and I were awarded the 2006 Nobel Prize in Physiology or Medicine—was not something that anyone was looking for. We knew, based on some early and unexpected laboratory observations, that there was something puzzling going on, and we grew more excited over time by what we were seeing as we tried to understand. RNA interference went from being a puzzle, to being understood well enough for us to publish a paper in the prestigious journal *Nature* in 1998, to being applied as a tool for treating human disease, to being recognized with the Nobel Prize, in just 8 years. The research and the discovery were all the more exciting to us because it was all so unexpected.

This could happen only because we are in an era unprecedented for the potential for scientific discovery. The investments in science made in the late 1990s and the first years of this century opened vast opportunities for science and scientists: universities built research labs and trained and hired new young scientists—like myself and Andy—who in turn made new contributions that other scientists learned from and expanded upon. The investments in facilities and training and the tools of research were the investments that led to the sequencing of the human genome—the mandatory first step in realizing the dream of interfering with disease at the genetic level. RNAi has tremendous promise for building on the work of the Human Genome Project, but only if further research is funded and allowed to continue. Importantly, information, the universal currency of science, now flows effortlessly and almost instantly around the globe. Consequently, the pace of discovery is picking up worldwide, increasing the opportunities for discovery but also increasing the competition for U.S. laboratories. If we do not increase the U.S. investment to keep pace with these opportunities, then we will see future multibillion dollar technologies like RNAi discovered and developed abroad. If we don't act now to increase science funding, other countries will capitalize on the investments we, the American people, have made in funding science over the past decades.

At the University of Massachusetts, we have established an RNAi Therapeutics Center to further capitalize on this momentum and our own particular expertise in the field of RNAi-based gene silencing. The vision for this Center emphasizes facilitating and promoting clinical and translational research and ultimately developing the next generation of powerful drugs to treat a broad range of diseases including cancers, Alzheimer's, diabetes, heart disease, and many other areas in which my renowned UMass colleagues have already dedicated years of work.

At UMass, there is a strong belief that science, and research, do truly matter, for a much larger reason than prizes or prestige: science matters because no one knows from where, or how, or based on what unpredictable series of events, the next breakthrough might come, and there has never been a moment in human history with more opportunity or greater need for advances in the life sciences than right now. This isn't science for the sake of science, but science for the sake of medical advances and lives to be saved.

This is just the beginning! The confluence of the energetic students and innovative young scientists trained in the last two decades, with the investment in facilities and resources, combined with the discoveries of the past few years, all flow together to create a perfect moment of opportunity. But just at the time when we should be investing in science at an unprecedented level, we are not. Just at the moment when we should be capitalizing on the investments of the past decade, funding for basic research is in decline. If Andy and I had been faced with today's funding climate 10 years ago when we applied for support for the work that led to the discovery of RNAi, I don't think we would have received that support. What other discoveries—what work like RNAi, what research that will advance it in ways we can't even imagine—will be missed, because we stepped back from the opportunity?

Thank you. I will be happy to take your questions.

Senator PRYOR. Dr. Mather?

STATEMENT OF DR. JOHN C. MATHER, CHIEF SCIENTIST, SCIENCE MISSION DIRECTORATE, NASA

Dr. MATHER. Yes, hi. Thanks for having us all come to talk with you. We hope we can answer your questions.

I'll just say a few things about what I've seen in my life that seem important to the future of the Nation.

Now, one is the astonishing opportunities that we now have. Astronomy has brought forward the possibility of knowing the history of the universe from the beginning until the formation of planets like ours. So, this huge enterprise now enables us to tell our own story and discover our history. And I think it's a very exciting thing for students to see this as the amazing intellectual challenge that we now have. And it's deeply important to people's sense of who they are, to know how we got here. And there are so many things to know about it from astronomy before we hand it over to the life sciences to say, "Well, what else can you tell us about that?"

So, it's exciting for students. It's a wonderful way to reach out to the public to get youngsters excited about science. And it was important to me, it still is important to me. I'm doing what I can. So, there's the pull of people into science and technology, to show them the excitement.

There's another thing that we do to try to get people in, and that's to make sure they get good education opportunities and their requirements and tests. And I think that's a little harder to manage, because I think threats of punishment are less effective than enchantment and excitement about science.

But, third, I think there's a huge opportunity that we now have to tell our young workforce what's going to happen. You know, if they see that funding is steady or going up with inflation, then they say, "Aha, there's a career for me in science, if I want to do that." And so, it's very important whether we've got our foot on the accelerator or our foot on the brake, because it affects the whole future of our workforce.

So, kids are smart, they can tell whether science is going to be a great career for them or not. And so, you've heard specific examples about biologists who have to spend many years being postdocs, and then they don't know if they'll ever get a job. I think it starts long before that. Kids in grade school and high school can sense whether there's a life for them in the technical careers that we find so important for our country.

So, thanks.

[The prepared statement of Dr. Mather follows:]

PREPARED STATEMENT OF DR. JOHN C. MATHER, CHIEF SCIENTIST, SCIENCE MISSION DIRECTORATE, NASA

Mr. Chairman and Members of the Subcommittee, thank you for the opportunity to appear today along with the other recipients of scientific Nobel Prizes, all representing the tremendous scientific achievements that the United States can make to the benefit of the world. I currently serve as the Chief Scientist for the Science Mission Directorate at NASA Headquarters, and am also the Senior Project Scientist for the James Webb Space Telescope at NASA's Goddard Space Flight Center.

My Inspirations

I am very proud of the support that our great Nation has given to science over the years, from both private and public sources. Benjamin Franklin was one of the great scientists of his time, and he put his personal credibility on the line to persuade the King of France to support the colonists in their fight for freedom. Thomas Jefferson sent off the Nation's first scientific expedition to explore the route to the Pacific Ocean. Industrial tycoons and taxpayer support in the 19th and 20th century built libraries and museums and the world's greatest ground-based telescopes, establishing U.S. leadership in education for the people and in astronomy in particular. When I was eight years old, I visited the American Museum of Natural History and the Hayden Planetarium in New York, and I was amazed to imagine that scientists could now hope to find out how the universe began, how volcanoes and earthquakes work, and how life might have come to be possible here on Earth. When the Sputnik was launched, the Nation saw once again that science was essential to our security, and suddenly public schools had science fairs, high school students went off to National Science Foundation-supported college courses over the summer, and NASA was formed to respond to the new challenge. Only a few years later, President Kennedy launched the Apollo program to show that the U.S. as a free nation was also a leader of science and technology. And James Webb, NASA's second Administrator, persuaded President Kennedy that the Apollo program should include serious scientific work for the good of the U.S., and was not just a foreign policy statement.

I was a young graduate student at the University of California in Berkeley when our astronauts reached the Moon, and soon after that I was working on measuring the cosmic microwave background radiation for my thesis research. This is the residual heat radiation of the great Big Bang that happened 13.7 billion years ago. I was supported in this work by several Federal agencies, and by a private scholarship from the Fannie and John Hertz Foundation. Only 6 months after completing my Ph.D. in 1974, I was organizing a proposal for submission to NASA to measure this radiation much better. As it turned out it was an excellent idea, and turned into a successful satellite mission called the Cosmic Background Explorer. Fifteen years later, in 1989, it was launched, and we immediately found very strong evidence confirming the Big Bang theory. And just 17 years after that, our work won the Nobel Prize in Physics for 2006. I believe that this prize recognizes the unique capability that the U.S. possesses, to put scientists and engineers together to build new tools that have never existed before, to discover what has never been known before.

NASA's Role in Promoting Science, Technology, Engineering, and Mathematics

As a nation, we must encourage our students to pursue opportunities in science, technology, engineering, and mathematics (STEM). NASA is in a unique position to offer groundbreaking opportunities in these areas to engage students and provide long-term career paths. The President's Vision for Space Exploration calls upon NASA to conduct robotic and human exploration of the Moon, Mars and other destinations, to conduct robotic exploration across the solar system, and to conduct advanced telescope searches for Earth-like planets around other stars. Other Presidential directives and legislative mandates instruct NASA to conduct Earth observation and scientific research and to explore the origin and destiny of the universe.

As a critical component of achieving NASA's mission, the Agency's education activities reflect a balanced and diverse portfolio of Elementary and Secondary Education, Higher Education, e-Education, Informal Education, and Minority University Research and Education. Through its unique mission, workforce, and facilities, NASA is leading the way to inspire interest in STEM careers, as few other organizations can. Our efforts have also made significant impacts in engaging underserved and underrepresented communities in STEM.

Accordingly, we are preparing the pathway for the next generation with great anticipation. These "explorers and innovators of the new millennium" must fully represent our Nation's vibrant and rich diversity. Furthermore, we will support our Nation's universities, colleges and community colleges by providing exciting research and internship opportunities that "light the fire" and "fuel the passion" for a new culture of learning and achievement in STEM.

NASA's educational activities are designed to inspire, engage, educate, and employ our Nation's talented youth. As contributors to achieving the Nation's goals, NASA is committed to three primary objectives to help improve the state of STEM education in our country:

1. *Strengthen NASA and the Nation's future workforce*—NASA will identify and develop the critical skills and capabilities needed to ensure achievement of the Vision for Space Exploration, science, and aeronautics.
2. *Attract and retain students in STEM disciplines through a progression of educational opportunities for students, teachers, and faculty*—NASA will focus on engaging and retaining students in STEM education programs to encourage their pursuit of educational disciplines critical to NASA's future engineering, scientific, and technical missions.
3. *Engage Americans in NASA's mission*—NASA will build strategic partnerships and linkages between STEM formal and informal education providers. Through hands-on, interactive, educational activities, NASA will engage students, educators, families, and the general public to increase America's science and technology literacy.

Within NASA science, a broad spectrum of education activities are sponsored, ranging from kindergarten to postgraduate levels. All NASA's science missions and programs must have an education and public outreach component. Through a competitive, peer-review selection process, NASA provides funding dedicated to education and public outreach to researchers. NASA also sponsors graduate and postdoctoral fellowship opportunities. In addition, the Agency is looking for new ways to provide increased opportunities for students to gain greater experience developing and launching their own science instruments, either in conjunction with science missions or through its suborbital rocket and balloon programs.

NASA is truly a premier Agency in its ability to reach out and inspire students. This is exemplified in part by the fact that NASA alone was responsible for 11 percent of *Science News* magazine's top stories—covering all fields of science—for 2006; this is an all-time record in the 34 years that this metric has been tracked. Important findings resulting from NASA's science programs ranged from new observations of familiar phenomena like the ozone hole, hurricanes, and rainfall, to the discovery of lakes of organic hydrocarbons on Saturn's planet-sized moon Titan, to the identification of new classes of planetary abodes across our galaxy, to the study of the Sun's magnetic field, showing it to be more turbulent and dynamic than previously expected.

In October 2006, NASA's twin STEREO spacecraft were launched to help researchers construct the first-ever three-dimensional views of the Sun's atmosphere. This new view will improve our abilities in space weather forecasting and greatly advance the ability of scientists to understand solar physics, which, in turn, enables us to better protect humans living and working in space.

From across the solar system, NASA's spacecraft have provided startling new insights into the formation and evolution of the planets. Images from the Mars Global Surveyor have revealed recent deposits in gullies on Mars, evidence that suggests water may have flowed in these locations within the last several years. The Mars Reconnaissance Orbiter, which began its primary science phase in November 2006, has not only taken extraordinary high resolution images of Mars at resolutions greater than any other mission to-date, but has taken incredible images of Opportunity and Spirit on the surface, and helped the Phoenix lander find a safe landing area. From its orbit around Saturn, the Cassini spacecraft recently found unexpected evidence of liquid water geysers erupting from near-surface water reservoirs on Saturn's moon Enceladus.

Additionally, the Wilkinson Microwave Anisotropy Probe (WMAP) Explorer mission, which I helped to propose, was able to gather new information about the first second after the universe formed, while the Chandra X-ray Observatory provided new and strong evidence of dark matter, and the Hubble Space Telescope identified 16 candidate planets orbiting other stars near the center of our galaxy.

Using instruments flying closer to Earth, NASA investigators flew 29 separate scientific instruments to 60,000 foot altitudes aboard NASA's WB–57F Canberra aircraft in the Costa Rica Aura Validation Experiment (CAVE). These airborne measurements, coupled with measurements from the orbiting Aura spacecraft, shed light on how ozone-destroying chemicals get into the stratosphere over the tropics and how high-altitude clouds affect the flow of water vapor—a powerful greenhouse gas—in this critical region of the atmosphere. This is fundamental basic work on the physical and chemical processes of the atmosphere.

Examples of important successes in our data analysis programs are also diverse. Astronomers combining data from the Hubble Space Telescope with data from ground-based and other space-based telescopes have created the first three-dimensional map of the large-scale distribution of dark matter in the universe. NASA researchers also found organic materials that formed in the most distant regions of the early solar system preserved in a unique meteorite that fell over Canada in 2000. And, using a network of small automated telescopes, astronomers have discovered a planet orbiting in a binary star system, showing that planet formation very likely occurs in most star systems. In our home solar system, scientists predicted that the next solar activity cycle will be 30–50 percent stronger than the previous one and up to a year late. Accurately predicting the sun's cycles will help plan for the effects of solar storms and help protect future astronauts. And a breakthrough "solar climate" forecast was made with a combination of computer simulation and groundbreaking observations of the solar interior from space using the NASA/ESA Solar and Heliospheric Observatory (SOHO).

As these and other results about our world and the universe pour in, NASA also continues to develop and launch our next generation of missions, and to support a vigorous scientific community via research and data analysis funding. In total, NASA currently is developing or flying a total of 93 space and Earth Science missions—far more than all of the other space agencies of the world combined. The Agency also supports over 3,000 separate research investigations in its science Research and Analysis programs, spending a total of approximately $600 million annually on scientific data analysis, modeling, and theory across the four disciplines of Earth and space science. Undergraduate and graduate students are active participants in these efforts.

Conclusion

We must encourage every segment of our population—girls and boys alike—from every walk of life, of every color and creed, to reach out and prepare for the opportunities of the 21st century. Building a pipeline of science and engineering talent to serve in the coming decades as we implement the Vision for Space Exploration to continue America's pre-eminence in space and aeronautics research and development can and must be done. NASA's mission is one of dreams, vision and exploration—characteristics that are ingrained in the American spirit and the underpinning of innovation and economic competitiveness. We intend to continue turning heads across the world by developing space missions and supporting scientific research that rewrites textbooks in all of our science disciplines, thus inspiring the next generation of students.

Again, thank you for the opportunity to testify today. I would be pleased to respond to any questions you or the other Members of the Subcommittee may have.

Senator PRYOR. Thank you.

Dr. Smoot?

STATEMENT OF GEORGE SMOOT, PH.D., SENIOR SCIENTIST, LAWRENCE BERKELEY NATIONAL LABORATORY, PROFESSOR OF PHYSICS, UNIVERSITY OF CALIFORNIA, BERKELEY

Dr. SMOOT. Senator Pryor, Senator Stevens, distinguished members of the Committee, including my home-state Senator Barbara Boxer, thank you for holding these important hearings and for recognizing the importance of a vigorous scientific enterprise for America's health and vitality. I share that interest, and I want to support your efforts.

I am a senior scientist, both at a national laboratory and at a university, and I have had a tremendous positive experience from both of those institutions. They're both very important parts of the scientific enterprise and to the country. I may be unique in the sense that I have split funding from three of the Federal agencies—the Department of Energy, NASA, and NSF. All of these have been vital in the development of scientific advancement and research. Each has fulfilled a vital role.

I encourage you to think about a broad spectrum, of the funding of science, because all of science is a fabric, and we never know what discoveries may arise. You mentioned the human genome which came originally from physical discoveries and computer science discoveries, and then were applied in the medical region. You have example after example of that.

John and I both were interested in studying the universe. I recalled during my childhood, as I started to ask the question, "How did we turn into scientists? How did we get into this channel?" It goes back to riding in my family car, and seeing the Moon out the back window, and the Moon follows us across the state, and so I asked my parents, "How does that work?" And they explained that it follows every car.

[Laughter.]

Dr. SMOOT. That was just so startling to me that I've always looked at the sky and looked at the world as something wonderful that could be explained rationally. Even though I've learned a lot since then, I still have that curiosity. I'm thrilled to think that young kids still do too, that they're asking the same kinds of questions. I believe that preparing the next generation is extremely important. I'm using part of my resources and stature as a Nobel Prize winner to try and start a teacher's academy for middle and high school science teachers, and to try to bring about the public outreach of science in an integrated way, but also bring in the next generation of scientists, engineers and computer scientists, because the whole infrastructure really matters. Between the combination of steadily rising Federal funding in the environment and the appreciation of how important science is to the Nation, whether in solving crises or just making economic prosperity work, this will encourage young people to dedicate their lives to try to make this a better world.

[The prepared statement of Dr. Smoot follows:]

PREPARED STATEMENT OF GEORGE SMOOT, PH.D., SENIOR SCIENTIST, LAWRENCE BERKELEY NATIONAL LABORATORY, PROFESSOR OF PHYSICS, UNIVERSITY OF CALIFORNIA, BERKELEY

Chairman Kerry, Ranking Member Ensign, and distinguished Members of the Committee. Thank you for holding this important hearing and for recognizing the importance of science and scientific achievement to America's health and vitality. It is my honor and pleasure to participate in this inquiry into the critical role that science plays in the life of our Nation and the world.

My name is George Smoot and I am a Senior Scientist at Lawrence Berkeley National Laboratory and a Professor of Physics at the University of California Berkeley. I am perhaps unique in having received roughly comparable and vital support from the Nation's three primary physical science agencies: DOE, NASA and NSF. As a scientist at Berkeley Lab and a professor at UC Berkeley, I benefit from the great advantages provided by a world-class national laboratory and one of the world's great research universities. Both play critical roles in promoting America's and the world's scientific advancement through internationally recognized research, rigorous education of future scientists, and unique scientific tools and resources. Both have also played critical roles in my career as an astrophysicist, and in my work that led to the 2006 Nobel Prize in Physics, which I shared with my distinguished colleague and fellow witness here today, John Mather.

I was awarded the Nobel Prize for my role in discovering experimental evidence for the "Big Bang," the primeval explosion that began the universe. This evidence was a map of the infant universe that revealed a pattern of miniscule temperature variations—"hot" and "cold" regions with temperature differences of a hundred-thousandth of a degree. These temperature variations, created when the universe was smaller than the smallest dot on a TV screen, are thought to be the primordial "seeds" that grew into the universe of galaxies and galaxy clusters we see today. The "map" of the universe that we created was produced in 1992 from data gathered by NASA's Cosmic Background Explorer (COBE) satellite.

It was exciting work. It was an exciting time. It was a time that ushered in what some call the Golden Age of Cosmology.

Since our COBE results, more amazing discoveries have been made. We continue to make maps of the universe with increasing accuracy, revealing more than we ever imagined. We now know that there is something that makes up roughly three-quarters of our universe about which we have no clue as to what it is. We call it Dark Energy for lack of a better name, and it is driving the universe to expand at an accelerating speed, contrary to the expected force of gravity slowing the expansion down and ultimately pulling the universe back in on itself.

New maps also reveal the existence of Dark Matter. Although it is estimated to make up a fifth of the universe, we also don't know what it is. Perhaps this unknown matter will someday be viewed through particle physics experiments, or be revealed through even more accurate maps of the universe. What we are sure of is that there will be new discoveries that continue to surprise us, yet will lead us closer to a fuller understanding of the universe and the properties of matter and energy and space and time.

The discoveries that John and I made, as well as those made by others, are not the result of singular endeavors. They rest on the shoulders of many individuals and are made possible by funding from more than one Federal agency. It certainly took a large group of committed scientists, theorists, technicians, and engineers to uncover the secrets of the infant universe. And, it took significant Federal funding.

America's innovation stems from the creativity that institutions like Berkeley Lab, UC Berkeley, U Mass, Stanford and Goddard Space Flight Center encourage and nurture in their students, researchers and professors. It stems from the intellectual freedom that only inquiry at the most basic and theoretical level of science provides. It stems from the commitment of Federal investment in the education of our children, the research of our investigators, and the development and maintenance of our scientific infrastructure. Science is an organic enterprise and does not exist in a vacuum. Science flows from its environment and is nurtured by steady funding and new young educated minds. If adequately supported these ingredients incubate and grow. They lay the foundation, the seeds, for the next generation of discoveries and innovations.

My early work as a post-doctoral physicist at Berkeley Lab was funded through the United States Department of Energy's Office of Science. I had the very great fortune of working with legendary scientists. Nobelists like Luis Alvarez encouraged me to "think big" and then gave me the space and freedom to do so. It was the funding from DOE that provided the foundation that allowed my work to progress. It enabled me to build my expertise and to organize the necessary team to tackle the hardest questions.

One point that I hope to leave with you today is that the U.S. Department of Energy is the major funder of the physical sciences in the United States. What does that mean? It means that DOE is the largest investor in the development and maintenance of our Nation's scientific resources, both human and infrastructure, in the research fields of chemistry, astronomy, all forms of physics, material sciences, and more. From its national scientific user facilities, such as synchrotron light sources, electron microscopes and particle accelerators, to programmatic research funding at its national labs and at research universities, DOE is supporting the underpinnings of American innovation.

The Department of Energy has also played a unique and critical role in training America's scientists and engineers for more than 50 years. I am an example of this support, as are many scientists of my generation. These scientists and engineers have made major contributions to the United State's economic and scientific pre-eminence. The nation's grand challenges, such as our current and future energy and environmental needs, will only be solved through scientific and technological innovation developed by a highly skilled workforce. The DOE's Workforce Development for Teachers and Scientists program is a catalyst for the training of the next generation of scientists. Through this program DOE national laboratories provide a wide range of educational opportunities for more than 280,000 educators and students on an annual basis. It is particularly important that we continue to extend and expand such opportunities to our students and, critically, to our teachers of science, technology, engineering, and mathematics. The entire science education infrastructure from K–12 through undergraduate students, and graduate students to postdoctoral scholars is the pipeline of future scientists and technologists. The educators, mentors and role models are the pumps that bring them along, prepare and excite them for their challenging and rewarding work.

However, as I intimated earlier, research and scientific training is underwritten by more than just funding from DOE. In my case, I have been honored to receive funding from the National Science Foundation and, of course, from NASA. Each agency played a crucial role in my development as a scientist and in the development of the programs on which I worked.

My group has received substantial funding from the NSF over many years that included support for graduate students and postdoctoral scholars, as well as access to NSF sites and facilities, such as the South Pole station. In fact, NSF funds probably exceeded or matched DOE funding of my work over the years.

In the mix of Federal support for my research, DOE funding served two incredibly important roles: (1) stability and longer-term risk, and (2) development of novel instrumentation later used on NASA platforms (aircraft, balloons, satellites) and at NSF sites. DOE provided steady and reliable program funding that allowed development of new concepts, instrumentation and ultimately fields. NSF and NASA funding was in general for specific projects or relatively short, and well-defined, research objectives (often prototyped with DOE funds). The NSF could be counted on to be interested in funding specific observations or developing new approaches that were linked to their program disciplines. Like DOE, NSF also liked to involve graduate students and undergraduates in research and often provided modest additional funds for that purpose. This activity helped funnel a number of bright young students on into graduate school and Ph.D. programs.

A very critical result of NSF funding was the creation of the Center for Particle Astrophysics. This center revolutionized the approach to the field. Now essentially every major first-rate university has a cosmology center modeled after it. The Center brought together a number of groups and institutions to push forward our understanding of Dark Matter and the accelerating universe, leading to the realization that Dark Energy makes up the majority of the Universe. The vibrancy of the combined programs of science and people, in addition to education and outreach programs, had a profound effect of productivity and creativity. It impressed all who saw it. Because of its success, the NSF has continued and expanded their center programs.

This illustrates my second point that I hope you will take to heart and leave here today remembering. America's scientific leadership and capacity for innovation stem broadly from the Federal Government's investment in a rich portfolio of research. Therefore, it is critical that all Federal funding of research be increased.

The scientific community is very pleased to see both the Administration's and the Congress' commitment to doubling the budgets of the NSF, the DOE Office of Science and of NIST. However, NASA's science budget, the NIH and DOD's scientific programs play important roles as well and should not be overlooked. Passage last week of Senate Bill 761, the America COMPETES Act, was a vital development and your work on this milestone legislation is recognized by all of us interested in American science. However, more must be done to raise the level of research funding significantly higher, and for all Federal research agencies.

The third and final point that I want to leave you with, is that Congress and the Administration must stay vigilant in your commitment to long-term, basic science that has no obvious immediate commercial application. Without this foundational research the really big, transformational discoveries and leaps in understanding will not occur. Basic science is the beginning of the innovation pipeline that leads to revolutionary technologies.

Take the prospects for advancements in energy research. Although progress in the effectiveness and cost efficiency of existing technologies, such as current methods of ethanol production and silicon-based photovoltaic cells, will happen, many believe that their learning curves are flattening out and that improvements will not get us to a place where significant inroads are made in carbon emission reductions or energy independence.

However, some of the most promising avenues for developing new, clean and revolutionary energy technologies are solutions rooted in fundamental basic science. For example, the DOE Office of Science is funding new bioenergy research centers that will investigate all of the scientific aspects of developing new cleaner fuels from biomass. We have known for a long time that we could produce liquid fuel from biomass; the problem has been that it is prohibitively expensive—we had to put the biomass in acid baths to free up the chemicals and then treat the resulting liquid, consuming a lot of energy while doing it. The research challenge is to find, and perhaps design and synthesize, new biological organisms and enzymes that will make the conversion process cheap enough to compete against the cost of gasoline. The new tools developed with the support of the Office of Science in genomics, computer modeling and synthetic biology put this within our reach, but much more work needs to be done.

In another example, the Office of Science is funding advanced research in nanotechnologies which offer the best hope for developing new energy storage systems that will be critical for making solar and wind economically attractive alternatives. Why is new nanotechnology so important for the future growth of solar and wind energy? These resources are available only while the sun shines or the wind blows, and that may be at times when they are not needed. Inexpensive ways to store that energy would make them useful resources all of the time. And why is nanotechnology so important to developing new energy storage systems? Our future success in energy storage depends on being able to build batteries that will be able to hold much higher charges, and be discharged much more rapidly, than present ones do; the way to achieve these advances is through advanced nanotechnology research—again, fundamental basic science.

In conclusion, I applaud the renewed focus that the Senate, the House and the Administration have placed on the need to maintain America's international competitiveness through nurturing innovation. Innovation, like science, is organic. No one knows where the next big "breakthrough" will occur and where it will lead us. No one can guess who will be the next young "Einstein" or "Edison" that takes the world in new directions. Therefore, it is critical that every child, every student, every researcher and every creative idea have the potential to blossom. You, as the stewards of our government, have the power of the purse and the legislative pen that can ensure America continues to invest in a broad portfolio of scientific endeavors, more aggressively invests in math and science education, provides the updated scientific infrastructure needed for 21st Century science, and encourages a research environment that embraces risks and awards creativity.

In times of crisis the Nation mobilizes its science enterprise. Whether in response to hostile outside threats, challenges to our preeminence, such as in the case of Sputnik, or as with today's energy-based climate and economic security concerns, the Nation turns to scientific and technological solutions. For future crises it is critical that the country keep a broad, vital and strong science infrastructure.

Even without the grand challenges to address, science impacts everyday life and makes our world a better place. It is clear to all that the economic prosperity, personal health, and world leadership of the country and its population rests upon the products of basic scientific research and the vitality of our science enterprise. The country's place in the world will directly reflect the level of its science. Any country that wishes to be a world leader must be a world leader in science.

Thank you, again, for the opportunity to provide testimony on this important topic.

Senator PRYOR. Let me, if I may, lead off on the questions, but what I'd like to do, for the Senators here, is, I'd like to have a free-flowing question-and-answer. I wasn't going to really do rounds, rather just a general discussion of things.

Likewise, my first question's just a question for the panel generally.

I understand, by the way, that we are going to have a vote around 4:30. I just got word on that. So, we'll figure that out when the time comes. We may have to slip out for a few minutes and we'll figure out if we're going to recess the hearing or exactly what we'll do.

Let me ask, I think that sometimes Congress and the public have a difficult time really understanding the importance of basic research. It's just not readily apparent to people sometimes. If I can explain to people in my state or people around the country, why it's important and what will be happening over the next 5 years, some of the emerging discoveries, and the applications of what you all do. Help us by explaining the significance of your research and why it's important to the quality of life, not just here in the U.S., but around the world, also maybe what products or you know, what may flow from that out on the marketplace.

I'll just throw that out to everybody.

Dr. KORNBERG. Let me explain in the following way. A good example that everyone knows about are the benefits of modern medicine. And there are few, if any, of us who don't either owe our health, or even the lives, of family members to modern medicine. It's worth bearing in mind it's only 100 years old. It wasn't much over 100 years ago, the only cure for disease was bleeding. And then, if you look back at the history over the last hundred years, what you discover is that virtually every major medical advance was made by the pursuit of knowledge for its own sake, and not for the purpose of advancing medicine. And to give you some examples: X-rays, antibiotics, medical imaging—for example, magnetic resonance imaging—recombinant DNA. These advances were all due to the pursuit of knowledge for its own sake. There is no example that I know of, or that I believe can be cited, to the contrary.

So, the lesson of the history is clear: If you wish to improve human health in the future, there is one, and only one, way to do it. If you wish to cure AIDS, if you wish to cure cancer, if you wish to cure Alzheimer's, it will not be accomplished by a targeted approach directed toward the ravages of that disease. It will only be accomplished by the unfettered pursuit of basic knowledge. Discoveries will be made, quite unintentionally, that eradicate these diseases.

Dr. FIRE. But one aspect of—if I may, one aspect of this that's worth stressing is that, as scientists we have a responsibility, when we talk about the consequences of our research, to talk about both the wonderful possibilities and also the limitations and challenges. And so, anytime we say, "This is what's going to be happening in 5 years," if we knew what was going to be a good treatment for a disease, we'd want it now. But of course there's always a great deal of uncertainty to anything in the future.

One of the nice examples of this is the monoclonal antibody industry. This industry comes from a discovery in 1975 which resulted in the Nobel Prize for the British and German scientists. They developed monoclonal antibodies: very specific molecular machines that would target individual molecules. Everybody immediately thought, "These will be great as therapeutics." And there was a lot of "hype," so to speak. There was a lot of excitement. But initially it didn't work. We didn't know enough about the immune system at the time to be able to make monoclonals work as therapeutics. Years went by when some great ideas for companies that would start from this "tanked". Fortunately there was research that went on at that time that was very successful in the academic sector, because the companies that tried to do this weren't successful.

And then, starting in the mid-1990s, there was enough information to make monoclonals work. Now they're a major economic component of the biomedical industry. They're also a major medical treatment, particularly against different types of cancer, against macular degeneration, against other things. So, when we talk about the consequences of our research—and when others talk about the consequences of their research—it's often difficult to predict what's going to happen. And the investments that are made now probably aren't going to have an effect in 5 years. That, I think, is a realistic statement.

Senator PRYOR. Dr. Smoot?

Dr. SMOOT. Yes, I wanted to elaborate on two medical examples, because that's something people relate to.

First, I want to expand on the earliest one: X-rays. If you think that NIH or somebody would have funded Roentgen, who discovered X-rays, this did not and would not happen; he was trying to study whether radioactivity came from the sun. Why would you fund that for medical research? A month after he published his paper, the first X-ray machine appeared in the first hospital. Three months later, it was in 15 hospitals. It was so obvious looking at the picture of his wife's hand with the wedding rings and the bones that this is a way to look inside people without cutting them open. This was an immediate clear application. That's one example of a key medical discovery coming from way out in left field.

The other example that I'll give you is an example of what happens when the technology comes from an unexpected source and matures. This is something that will supposedly happen in approximately 2 years—it's on a 4-year plan, and it's on schedule: That is a new cure for malaria, which now kills annually 1.5 million people in the world today. It has been discovered there is a plant that will cure malaria—which is now resistant to quinine—so that's a serious problem in the world. People have realized how to take the gene from that plant and put it in bacteria, and then the bacteria will produce this cure. The World Health Organization is funding the combination of Jay Keasling, who is at UC Berkeley, his laboratory and a private company (Amyris Biotechnologies, Inc.)—to build this, and they claim that in 2 years they will deliver the cures for malaria at 25 cents a dose.

That's really impressive. But what it tells you is, once you truly understand a disease, and understand the cure—the molecular cures and so forth—you can do it at a reasonable price. When you look at the escalating healthcare costs, you realize that one reason they are so high is we have an aging population that's living longer. This is due to our successes, but we still have healthcare problems. Once you understand the diseases, you can treat them at a much lower cost, and that's the only way we're going to contain the fact that people are going to live to 120, right?

Senator PRYOR. Anybody else want to take that?

Yes?

Dr. MATHER. Yes, I'd like to, sort of, move the discussion over toward the Space Race, which is almost 50 years old now. It began with a plan for pure curiosity-driven research in the International Geophysical Year. Auroras were of great interest. We wanted to know local things about our star, and our neighborhood around the Earth. And I was excited about it. But, you know, Sputnik went up as part of that international plan, and suddenly this country was absolutely petrified. So, it had a curiosity-driven program, which was international in nature, had instantaneous international ramifications, and obviously led to huge investments, eventually, in communications, in weather satellites, so we know whether it's going to rain, in computers, in monitoring the rest of the world with satellites, in astronomical capabilities to look out at all wavelengths where the air blocks our view.

Now even moving on toward looking down at the Earth and telling whether it's getting warmer or colder or what, and what are the long-term trends on the Earth. And even a military application, the Global Positioning Sensor System, is now something everyone can have on a cell phone. And it's a completely amazing thing that it was all kicked off by curiosity-driven research.

Senator STEVENS. I have been around here for a long time, and I've probably added more money to more budgets for basic research than any Senator in history. But I also see that we have, now, enormous foundations, enormous private-sector money—Gates, Google, Buffett, you name them—enormous sectors of money. They don't seem to be going into this field, because they see the amount of Federal money we're putting into it. What do you say about that? Is there a balance there somewhere? And how much do you—have you gotten private money for—to supplement your Federal grants? Where is the balance, in terms of society, for basic research, when we have these enormous funds out there, and they don't want to put them in where you are, because the Federal Government's already monopolizing the field?

Dr. KORNBERG. You know, that's the—it's very important to bear in mind that the Federal Government has instituted, first of all, a system for the distribution of funds, which is uniquely effective——

Senator STEVENS. You're not answering my question, now. I'm—I don't have a lot of time. Please answer the question. Is there a balance between, and do you seek, private funding as you're seeking——

Dr. KORNBERG. OK.

Senator STEVENS.—an increase in Federal funding?

Dr. KORNBERG. So, I wanted to explain that, first of all, the private funds are far, far less, and, in no way, adequate. The private funds are less than 10 percent of what is available—what the Federal Government spends, which is, itself, presently inadequate.

Senator STEVENS. Federal Government only entails about—in my last memory, about—somewhere around 11 percent of the GNP. Now—so, let's not tell me that there's more——

Dr. KORNBERG. I'm sorry.

Senator STEVENS.—more funds in the Federal Treasury than there are out there in the private sector. There are enormous sums. I just want to—do you seek increases in private-sector funding as you're seeking—here—I don't disagree with doing that, but are you seeking similar increases from the private sector?

Dr. KORNBERG. Please understand, there are two components to the private sector, the foundations and companies. The foundations have far less funds, much less than 10 percent of what the Federal Government makes available, which is, itself, inadequate. Second, companies will never invest in research that requires 25 to 50 years to do. They are looking for short-term gain. And so, it's hopeless to look to them. On the contrary, they look to the Government, and they look to us, for the lifeblood of their industry.

Senator STEVENS. Well, I'm not totally satisfied with that, because we've doubled research funding for NIH, we've doubled research funding in basic sciences since I've been here—more than doubled. We have not seen the emphasis of going to the private sector for support for basic research that existed before all this Federal money came in. When I first came in, there was very little Federal money going into basic research. Very little. DARPA was one of the first real sectors of increased Federal funding, and that's within my lifetime, within my time here in the Senate. So, before that, private sector—the research base of this country was the private sector. But it seems that as we increase Federal funding, they pull back. And I'm sincere in asking you——

Dr. KORNBERG. I understand.

Senator STEVENS.—I think you should be seeking additional funds from the private sector. Those foundations are gigantic. And several of them gave $30 billion last year to various functions. Now—and what you're talking about is not $30 billion. We haven't increased your funding by $30 billion.

Dr. KORNBERG. I can't speak to the $30 billion, because I'm unaware of funds even approaching that scale being available from any other source to our research. But in regard to the—seeking funds from the private sector, we struggle all the time. When Federal funds fall short, as they have done of late, and people are leaving our field, we try desperately, and we appeal to every other source. We do obtain small amounts of money, occasionally, from some non-Federal source, but there's no way they can now, or ever will, match, for value, as well as for quantity, what is distributed by the Federal Government.

Senator STEVENS. Federal Government doesn't have any money, except what it takes from you. So, don't tell me we've got more money than the private sector. We don't. The question is how much is going to be dedicated to the kind of research that you want us to do, and do so well. I just think there ought to be some balance here, in terms of the amount of money you ask us to provide from the taxpayers and the amount of money you go out and solicit——

Dr. KORNBERG. Please——

Senator STEVENS.—from the private sector.

Dr. KORNBERG. Please understand, the private sector makes an enormous investment in development, based upon our discoveries. They invest massive amounts—I think, far beyond the $30 billion to which you alluded—in exploiting the discoveries made from Federal funds to multiply the value of that Federal investment.

Senator STEVENS. Well, don't shoot the messenger, but we're hearing this. We're hearing that we're reaching the point that we're putting up a lot more taxpayers' money for things that the private sector could, and should, do.

Dr. KORNBERG. Well, I would respectfully suggest that the public—private sector is trying its best, and that the argument that has been put to you on those lines is mistaken.

Dr. FIRE. I can, maybe, tell a little story. We had a research project that was certainly not ready to be funded by NIH. And there was a private foundation in that field that funded new work. Ours was long-term research and we said that this wouldn't be really valuable for about 10 or 20 years. So, we put in an application. That agency had sent out a request for proposals, and there were hundreds that came in, all related to that particular area of science—medicine. And they had to make a decision, in the short term, on what they could fund—what they felt would benefit what was essentially their client base, which was a specific set of people that were affected now with the disease. Our proposal was certainly not amongst those that would be most highly beneficial to anybody that has the disease now. And, of course, it wasn't funded by the foundation. I think that the private sector, both foundations and companies, are doing the best that they can, but they have limitations, too. If you look at their ability to fund really basic research into fundamental questions, it's quite limited. They look to themselves sometimes to leverage given areas, where the research will get to a point where then it's federally supportable. They look to go into areas that might be difficult to be funded otherwise.

Also remember that foundations and industry look for support from the Government—this includes industry looking for early leads on developments that could be useful for therapeutics that could be useful and economically beneficial. They (foundations and companies) also look for guidance from basic scientists that can work in a setting where there isn't a requirement to make a profit or focus on one disease.

I think if you were to get rid of a certain fraction of the NIH budget, and hope that this would be taken over by the private sector, you wouldn't get the same kind of science done, and both the companies and foundations that would be trying to take up the slack, and the scientists trying to do the work would be unable to do the kinds of work that they need to do. And so, the assumption that anyone could "take up the slack" in federal funding would hurt both the basic and applied at the same time.

Senator PRYOR. OK. You all may have wondered what these lights are and what these buzzers are. That means we're in a vote, and we're more than halfway through the vote now.

So, what I'm going to do is recess the Committee for 5 to 10 minutes. I think I'll be back within 10 minutes. And we'll pick up where we left off.

So, we'll be in recess for—subject to the call of the Chair.

[Recess.]

Senator PRYOR. We'll call the Committee back to order. Thank you all for being patient. We just had a vote. And now, see the two little lights on, that means we're in a quorum call, which means they're trying to figure out what to do next on the floor.

Let me just run through a few questions. And, again, I understand that you all need to go to the White House so maybe 10–15 more minutes max, of questions, and then we'll let you all get on your way.

Let me ask a couple of questions here, quickly. And, again, just kind of free-flow an answer, whoever wants to jump in, we'd love to have your thoughts. Like I mentioned, your statements will already be part of the record, so please know that those points have been made publicly.

We talked about funding basic research, and the lack of risk-taking on the part of Federal agencies. The NIH budget doubled in the 5 years from Fiscal Year 1999 through 2003, but has remained flat since then. The percentage of first-time applicants for NIH investigator-initiated grants has been steadily falling. We see the same problem at the NSF, where new investigators have a lower success rate than overall NSF grant applications. What steps should the Federal Government be taking to ensure that high-risk, high-reward research is still being funded? So, who wants to jump in on that?

Dr. KORNBERG. There's a—such a simple—if I may——

Senator PRYOR. Go ahead.

Dr. KORNBERG.—simple—there's an answer—a simple answer to that question at one level in regard to NIH, and that is to restore what was lost during the period of flat funding, and then maintain a steady and reliable budget after that time. It's—the—filling the immediate—the gap that has been created, the emergency that has arisen, but it's first necessary to keep some of the best investigators still in the system who would otherwise be lost, and then, after that, simply to create a climate of reliability so that people know that if they undertake research that may take a very long time, and that is risky in nature, they won't be cutoff in the middle and unable to complete the work.

Senator PRYOR. Right. Anybody want to add anything to that?

Dr. SMOOT. Yes, I think that when you think about what reliable funding means, it means going up at least as fast as inflation. In a reasonable enterprise, you would expect that science funding would go up with either the overall Federal budget or the GDP, just because you're expecting science as a long-term investment that returns itself in the economy. If you want the economy to keep growing, you have to keep, you know, your investment level up at that appropriate percentage.

Senator PRYOR. Sometimes here in Washington—I don't want to throw stones at anybody, but let's just say—sometimes here in Washington, when we talk about research, it—we naturally, sometimes, talk about the ethical use of the research and the things that flow from that research, and risks that are involved. And, you know, one of the most high-profile controversies we've had is embryonic stem cell research. But something that we've been working on in this Committee, the full Committee, is nanotechnology and some of the environmental risks and challenges there, that are—some of those are very unknown at this point. So, I have a question, again, for you. When Congress, or when the President, puts limitations on research, either through Executive Order or through national law, what effect—or maybe it could be just the policies that the various Federal agencies have—but what effect does that have on you, in terms of conducting research, peer review, scientific integrity? What does that really do to you?

Dr. FIRE. Maybe I can say something there. I think there have to be limits on research. There have been horrible experiences over history where research without any kind of oversight has caused trouble. So I think all of us accept that there are societal rules that have to be made at a governmental level and an institutional level. That we have to follow these rules, I think we're all comfortable with. We will work as best we can within those limits to deliver the science and the cures and the economic benefits. This is a conversation. If there is a case where we feel that a decision has been made that has really hurt—has a negative consequence, it's something that we should be communicating back to this body, or other bodies, saying "Here is something where a great opportunity is being lost." And then, the debate has to occur on the public level, not just one way, but a dialogue. We can't say, "As scientists, you need to do this." These are really public questions to wrestle with. And so, we will work within whatever constraints we're given by society to do the best science we can.

Senator PRYOR. OK. Let me say——

Dr. SMOOT. But let me interrupt, because——

Senator PRYOR. Yes, go ahead.

Dr. SMOOT.—in the case of stem cell research, you actually see that one of the things that happens is some people move their research overseas into communities where it was not constrained. And those are the places that it's going forward. The reason they did it, it was—they believed that it was really going to be extremely valuable, in terms of the advances that could be made. What you may also see is people going overseas for medical treatment.

Senator PRYOR. Right.

We've been joined by Senator Klobuchar.

Let me ask one more question, and then I'd like to turn it over to her if she has any questions or comments.

Another debate that we have here in Congress is not directly related to you, but, I think, does touch on your world of research and academic pursuits, and that is immigration policy. This is something that—last year, there was a lot of discussion about immigration here in the Congress. And from my standpoint, unfortunately, it tended to focus on border control and Hispanic individuals entering the country illegally. That seemed to be the brunt of the rhetoric. But I know that immigration plays a key role in your world, in the world of research and academia. Give—just give us some general thoughts on what you think the immigration policy should be in this country as it relates to you. I mean, I understand everybody has strong feelings about lots of different pieces of immigration, but just as it relates to what you all do, what type of immigration policy should we have?

Dr. SMOOT. I have an anecdote. I have five graduate students, and three of them come from foreign countries—one from Korea, one from Mexico, which comes directly to the Hispanic issue—he happens to be extremely good. One of the things you should realize is that Mexico graduates more engineers than the United States does. When you start thinking about who are you letting into the country, you start thinking about what skills you need. The other anecdote at that level—and I can do one on both sides—is that I have watched the applications to graduate school over 25 years, and in the beginning we would get, like 100 applicants from foreign countries, and we would get on the scale of 600 from the United States, now—and, of the 100, a lot of them were unqualified, but now we get, like 500 from overseas, and we get 400 or 500 from then U.S., and the ones from overseas, on the average, are better qualified.

Unfortunately, we have seen a partial failure to attract and educate young people in science in the United States, and we've seen that the way we get scientists and engineers and computer scientists in the United States is by importing skilled people from abroad and trying to keep them here. So, it's actually vital to the scientific enterprise and the economic enterprise to the United States to be able to bring skilled, intelligent people into the country and make that process work smoothly. So, the issue always was one of—first, of getting bodies into the U.S., but now of getting skilled people who are going to contribute to society, and make them welcome, and give them opportunity.

Senator PRYOR. Any other comments on that?

Dr. FIRE. I think——

Senator PRYOR. All right. Well——

Dr. FIRE.—that making non-citizen scientists welcome is a really useful goal. Because many of our scientists (including students and postdocs) have to go through the system of immigration, we have a vested interest in making that system work. I think all of the caution that we take is necessary, but what do our guests see now? As they see some of the difficulties that the immigration system has, some of the lack of respect that they're shown as they go through the system—this is really problematic. And so, some kind of a personal treatment from people in the immigration services—where they're welcomed—they should find, "We need to do this careful screening, but we also welcome you into in our country." Even though it might not change any specific policy, that would make a huge difference in our ability to bring in talent. As the first agency they see when they get to this country, or as the first contact as they're planning to go to this country—the immigration machinery could make a huge difference in our ability to attract the best people.

Senator PRYOR. Senator Klobuchar?

STATEMENT OF HON. AMY KLOBUCHAR, U.S. SENATOR FROM MINNESOTA

Senator KLOBUCHAR. Thank you for coming. Congratulations on your accomplishments and your prize. I come here having the only prize I've ever won was Ms. Skyway News of March 1988.

[Laughter.]

Senator KLOBUCHAR. So, I'm in your league, as you can see.

[Laughter.]

Senator KLOBUCHAR. I wanted to talk to you. I come from Minnesota, where we believe in science, the home of the Mayo Clinic, and the University of Minnesota, and I appreciated what you were saying about stem cell research. We've actually lost some people from the University of Minnesota to Europe because of the limitations on the research. I also was listening to you—Dr. Smoot, about the immigration issue. I've had the CEO of Medtronic from Minnesota tell me how it was getting difficult for them because of these issues and things. When graduate students were in, that they wanted to keep on, that they had some issues in trying to do that. So, I think that's something that cries out for comprehensive reform.

I wanted to ask a little bit about our own education system. I have a daughter who's 11, and is actually in Mark's daughter's class, and I've seen some good science going on in the Arlington public schools in Virginia. I wonder what you think needs to be done with our public schools to get us into the direction so we can have more Americans sitting at a table, like you are today.

Dr. MATHER. I'd like to address that question, just for a moment. We, as a nation—indeed, as a species—really, the most important thing we do is pass knowledge to the next generation. And as a democracy, this is incredibly important. We, as a people, have to make ethical decisions related to technology, things like stem cell research, and we need to have people who understand the science involved so that they can make informed decisions about whether it's ethical or not. For example, I have a 6-year-old who has type I diabetes, and, you know, it's—it really brings home, when you or a loved one has a disease that could be treated with stem cell biology, for example, the importance of exploring these, and sometimes very complex ethical issues. I'm not taking a position, beyond saying that it's extremely important that we educate our young people so that ultimately we'll have citizens who can make informed decisions about the future of this country. And we're not doing a very good job of that.

In my state, we have Proposition 2½, where we cannot levy more than 2½ percent each year on our property taxes. Just yesterday, we took a vote in our local elections, and, despite extreme efforts to organize the "yes" vote, we failed to produce an override. Consequently, our schools, in the midst of a diabetes and obesity epidemic, are now charging our young people at least $225—this is going to go up—to participate in track. So, we have kids who want to run, and then—and now we're charging them extra money to participate in track. We're going to cut freshman athletics. We have a fifth-grade study hall. And this is happening all over the state, because—I know, I was deeply involved in this organization. I'm heartbroken today to have to be here, you know, not having that success behind us. But I'm also energized, because we need to redouble our efforts to fix this problem on a national level, on a State level, on a local level. It's going to take, you know, efforts on every level. And we're certainly energized in our state, in our local and our town of Shrewsbury, Massachusetts, to do what we can for our young people. They're the future. And let's face it, we're not handing them a very certain future, we're handing them a future that's very uncertain—I think, much more so than when we were young people. And we need to prepare them for that uncertain future, and we need to see that they have a great education. I don't have a solution, unfortunately.

Senator KLOBUCHAR. OK.

Anyone else?

Dr. SMOOT. I actually spend a fair amount of my time and some of my resources and have been doing for many years, but now boosted by having the Nobel Prize, I'm trying to address this education problem. Along with one of my colleagues, I am trying to create a teachers academy for middle- and high-school science teachers, and to couple that with a program (a new program in California), which is encouraging people to get a double degree in science and in education so they can become high-school and middle-school science teachers or math teachers. It's absolutely essential that we bring in quality teachers, and we get them to be enthusiastic, and keep them connected to the science enterprise so that they share the excitement and the enthusiasm that they have for the subject to their students. That will help bring them along. And those students may not become scientists, they may become engineers, they may become computer scientists or whatever else, but they're the technological backbone of what the society will be. Right now, the short-term solution is, we've got to import; the long-term solution is we have to bring our K through 12, and then beyond, education up to the world's standards. Right? You notice we're 26th now. So——

Senator KLOBUCHAR. Right. I was just thinking of what Dr. Mello had said. I decided that we had a breakthrough at our home last night. My daughter, the science she had before she came to this school wasn't as strong, and last night, after living through Mrs. Migurca, she goes, "Mom, I think what Mrs. Migurca's saying is starting to make sense, it has everyday application in my life."

[Laughter.]

Senator KLOBUCHAR. And then she proceeded to talk about how many times we flush the toilet and that we were wasting water. But, in any case——

[Laughter.]

Senator KLOBUCHAR. I think that what I was saying, what Dr. Mello said, beyond graduating better students that go into science, I think that it's going to give them a better understanding of issues, like climate change and things like that, that's going to help them, whether they go into science or not, and then understanding stem cell research and some of these other issues.

My last question would be this. I understand I'm the only thing that divides you between this hearing and going to the White House, so we don't want the 98th most-senior Senator to hold you up on that journey, but——

[Laughter.]

Senator KLOBUCHAR.—I just wondered, the U.S. used to rely on major labs, financed labs—like AT&T and General Electric and IBM, to do a lot of our research and these national labs no longer exist. I'm just wondering if you think that DOE-supported labs at Los Alamos, other places, can serve as a replacement for these industrial labs, or if you think that we should be looking at other routes, as well.

Dr. SMOOT. I have a joint appointment between the Lawrence Berkeley National Lab, which is a DOE lab, and the University of California. That system works extremely well, having a national lab with cross-cutting professors who are in both places. We have about 200 to 300—I think 280—professors with joint appointments, along with a tremendous influx of students and postdocs. It keeps everyone refreshed, and it keeps science on track. The national labs, particularly the DOE labs, serve as a reservoir of basic science knowledge, but you also have NSF facilities and NASA centers that play important roles or more specific roles. When a crisis comes, like the energy crisis (of course, DOE is now Department of Energy, but it wasn't originally) or, in this case, in the biological sciences, Dr. Kornberg used the facilities in order to do that—they are certainly very important as a resource of talent and facilities.

There are a lot of national labs in the country. Are they all effective? Perhaps they could be restructured in some cases. But, in fact, they create a combination of basic research in universities which is extremely important. That's where the next generation will come from. It's where many good ideas originate. The expertise that exists in the national labs and centers, along with the ability to take on big projects and resolve important issues as they arise in the country. So we must do that. It's unfortunate regarding the economics, as in the case of Bell Labs. Since Bell was a monopoly, it could take part of its regulated money in order to support this national laboratory. Also, when IBM was a very rich and powerful company it could invest in the future. As the world economic climate changes, those things drop out, and it's really the Federal Government that has the primary role of doing basic research. When it comes to applied research, the higher you go up the chain, the closer to applications, the more the technology should transfer over into the private sector.

Senator KLOBUCHAR. OK. Anyone else?

Thank you very much.

Senator PRYOR. I want to thank you all for being here. Before I cut you loose, I want to say that it's really been an honor to have you here. And what we'd like to do is, every year, have a panel of the three winners—the three Nobel Laureates. And so, my last question is, do y'all have predictions for who will——

[Laughter.]

Senator PRYOR.—win next time? We need to get our invitations out for next year. So—seriously, do y'all have any predictions on any great stuff that's going on out there, either in medicine, chemistry, or physics? Is there a favorite out there? I know it's not quite like the Kentucky Derby, but——

[Laughter.]

Dr. MATHER. I think we have to plead the Fifth on that and take a——

Senator PRYOR. OK.

Dr. SMOOT. We also have a role that we get, also, to be nominators.

Senator KLOBUCHAR. Oh.

Dr. SMOOT. Right? So——

Senator KLOBUCHAR. You're crossing protocol——

Senator PRYOR. So, it's like the Academy Awards.

Senator KLOBUCHAR.—here, Senator.

Dr. SMOOT. So, we have to be careful about what we say.

Senator PRYOR. So, it's like the Academy Awards. Once you win the Oscar, for life you get——

[Laughter.]

Dr. SMOOT. You get a chance to put in——

Senator PRYOR. Wow.

Dr. SMOOT. Well, it's a very complicated procedure but you can propose people to be actually nominated. It's called "nominating," but it goes to a Committee after that, which then decides whether to present cases and so forth.

Senator PRYOR. Well, we'd like to put in a word for Minnesota and Arkansas.

Dr. SMOOT. Right.

[Laughter.]

Senator PRYOR. Listen——

Senator KLOBUCHAR. Thank you.

Senator PRYOR.—thank you all for being here. And I think we may want to do a very quick photo. Senator Klobuchar, if you want to join in that——

Senator KLOBUCHAR. Sure.

Senator PRYOR.—that would be great. And then we'll let you go. Thank you very, very much.

[Whereupon, at 5:17 p.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

Science is the basis of human progress. This field of knowledge allows us to understand the world around us and to continually transform and improve our quality of life. Today's essential technologies, such as mobile phones and air travel, are based on our understanding and mastering of scientific concepts like the electromagnetic spectrum and aerodynamics.

Since the Industrial Revolution, the United States has reaped the benefits of our investment in scientific research. American scientists have been at the forefront of discoveries that have changed the world. Barbara McClintock observed the transposition of genes, breaking new ground in molecular genetics.

John Von Neumann's work in mathematical logic laid the foundation for computers. And Richard Feynman expanded the theory of quantum electrodynamics. These are just a few examples of the American scientific contribution to world knowledge.

Our panel today reflects a cross-section of America's exceptional scientific leadership. This team represents a complete sweep of the 2006 scientific Nobel prizes, for the first time in more than 20 years, an impressive and well deserved accomplishment. Their hard work and persistence are largely responsible for this achievement. At the same time, I am sure our distinguished witnesses would agree that some credit is due to the American scientific enterprise. Our strong educational system and research infrastructure lies at the heart of this enterprise.

For decades our nation, which accounts for only 6 percent of the world's population, has produced more than 20 percent of the world's doctorates in science and engineering.

However, our system is in jeopardy. The National Academies' *Rising Above the Gathering Storm* report warns that the Nation is at risk of falling behind our international competition. According to the 2006 National Science Board Science and Engineering Indicators, 78 percent of science and engineering doctorates are earned outside of the United States. Almost half of the masters degrees awarded in computer science in this country went to foreign students.

We must take corrective action to ensure the United States does not lose ground in science and technology. Just last week the Senate passed S. 761, the America COMPETES Act. The legislation received 88 votes in the Senate.

That strong showing reflects how united this body is in recognizing the need to bolster the Nation's competitiveness. The bill calls for reinvestment in our scientific endeavor through increased funding for the National Science Foundation, the National Institute of Standards and Technology, and the Department of Energy's Office of Science. S. 761 also encourages broader participation in the science, technology, engineering, and mathematics fields, particularly by women and underrepresented minorities.

The accomplishments of this panel are impressive, and if we are hoping to replicate their achievement 20 years hence, the United States must seek continuous improvement in our science enterprise. I look forward to incorporating the recommendations of this esteemed panel into our legislative work this Congress.

RESPONSE TO WRITTEN QUESTIONS SUBMITTED BY HON. MARK PRYOR TO DR. ROGER KORNBERG

Question 1. You spoke about the challenge of funding basic research and the lack of risk-taking on the part of our Federal agencies. The NIH budget doubled in the 5-years from Fiscal Year 1999 through 2003 but has remained flat since then. The percentage of first time applicants for NIH investigator initiated grants has been steadily falling. We see the same problem at the National Science Foundation where new investigators have a lower success rate than overall NSF grant applications.

Can you describe some of the benefits to scientific discovery directly related to the doubling of the NIH budget and what will be the impact of the recent flat funding?

Answer. The doubling of the NIH budget elicited a remarkable response from the private sector. There was a surge in philanthropic contributions to universities and research institutes for the construction of new facilities for basic biomedical research, to be staffed by new young faculty who are the driving force behind scientific discovery. The stage was set for an explosion in precisely the sort of new information from which important new drugs and medical procedures are derived. The recent flat funding has undercut the promise of this truly exciting and crucially important development. The partnership between government and the private sector is in crisis. Not only have the new investigators gone largely unfunded, and in many cases driven from the field, but superb established investigators at the peak of their powers are finding it difficult, sometimes impossible, to continue with their work.

Question 2. What steps can the Federal Government take to ensure that high-risk, high-reward research is funded?

Answer. Two steps are critically important. First, a level of NIH funding commensurate with the doubling should be reestablished and increased as in the years before the doubling, to enable the natural growth of biomedical science. Without growth there is no entry of the new young scientists, trained in established laboratories, and most creative in their early years as independent investigators. Second, and no less important, NIH should be directed to devote most funds to individual investigator-initiated (RO1) grants, and discouraged from funding targeted toward specific diseases and funding of large programs targeted toward specific lines of research. History has shown that RO1 grants are the wellspring of discovery, while targeted programs are less productive or fail.

Question 3. How do we reconcile highly innovative, potentially transformative research with the peer review process for awarding grants?

Answer. Peer review works well when funding levels are adequate, and breaks down when funding is cut. The reason is that "highly innovative, potentially transformative research" is risky. Review panels become more conservative when funds are limited, and avoid all risk.

Question 4. Would programs similar to the NIH Director's Pioneer Award Grants work in other agencies?

Answer. The NIH Director's Pioneer Award Grants should be discontinued. To extend this approach to other agencies would be a terrible mistake. The NIH Director himself is superb. The Pioneer Award Grants, however, and also the programs targeted toward specific lines of research, undercut the proven, peer review-based RO1 approach. Those who have received a disproportionate share of funding through the Pioneer Award program are no more capable and no more likely to produce important discoveries than those who have not received these awards. The Pioneer Award and other such programs cause harm by depriving many dedicated, deserving investigators of needed support.

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