AMERICAN COMPETITIVENESS: THE ROLE OF RESEARCH AND DEVELOPMENT

HEARING

BEFORE THE

COMMITTEE ON SCIENCE, SPACE, AND TECHNOLOGY
HOUSE OF REPRESENTATIVES

ONE HUNDRED THIRTEENTH CONGRESS

FIRST SESSION

WEDNESDAY, FEBRUARY 6, 2013

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AMERICAN COMPETITIVENESS: THE ROLE OF RESEARCH AND DEVELOPMENT

WEDNESDAY, FEBRUARY 6, 2013

HOUSE OF REPRESENTATIVES,
COMMITTEE ON SCIENCE, SPACE, AND TECHNOLOGY,
Washington, D.C.

The Committee met, pursuant to call, at 9:34 a.m., in Room 2318 of the Rayburn House Office Building, Hon. Lamar S. Smith [Chairman of the Committee] presiding.

LAMAR S. SMITH, Texas
CHAIRMAN

EDDIE BERNICE JOHNSON, Texas
RANKING MEMBER

Congress of the United States
House of Representatives

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Committee on Science, Space, and Technology Hearing

American Competitiveness: The Role of Research and Development

Wednesday, February 6, 2013
9:30 a.m. – 11:30 a.m.
2318 Rayburn House Office Building

Witnesses

Mr. Richard Templeton, President and CEO, Texas Instruments

Dr. Shirley Ann Jackson, President, Rensselaer Polytechnic Institute

Dr. Charles Vest, President, National Academy of Engineering

U.S. HOUSE OF REPRESENTATIVES
COMMITTEE ON SCIENCE, SPACE, AND TECHNOLOGY

HEARING CHARTER

American Competitiveness: The Role of Research and Development

Wednesday, February 6, 2013
9:30 a.m. – 11:30 a.m.
2318 Rayburn House Office Building

Purpose

On Wednesday, February 6, 2013, the House Committee on Science, Space, and Technology will hold a hearing to examine the status of and outlook for America's science and technology enterprise, examining the impact of research and development (R&D) on the lives of the American people and looking ahead to potential breakthrough innovations for the future. Witnesses will discuss the historical context for American R&D, how it is divided between public and private investments, where the U.S. ranks globally on innovation and investment, and what the future may hold for American innovation.

Witnesses

- Mr. Richard Templeton, President and CEO, Texas Instruments
- Dr. Shirley Ann Jackson, President, Rensselaer Polytechnic Institute
- Dr. Charles Vest, President, National Academy of Engineering

Overview

The National Academies report "Rising Above the Gathering Storm" [1] in 2005 initiated a renewed policy debate on the nature of America's competitiveness stature and the increasing investment of other countries in both research and science education. Although the U.S. still remains the leader in annual total investments by both the public and private sectors, nations such as China and India are making substantial investments in R&D and promoting policies to attract innovative companies and educate a technically-trained workforce. The Science, Space, and Technology Committee will continue to take the lead on legislation to provide direction on federal R&D spending and STEM (science, technology, engineering and mathematics) education.

U.S. industry represents 62 percent of America's R&D investment, with more than three-quarters of industry R&D dedicated to development instead of research. By contrast, the federal government funds more than 60 percent of all basic research, characterized by longer-term activities that industry cannot afford due to the higher risks and expenses. The federal government supports approximately $140 billion annually in R&D. More than half of the federal basic research is conducted by universities.

[1] http://www.nap.edu/openbook.php?isbn=0309100399

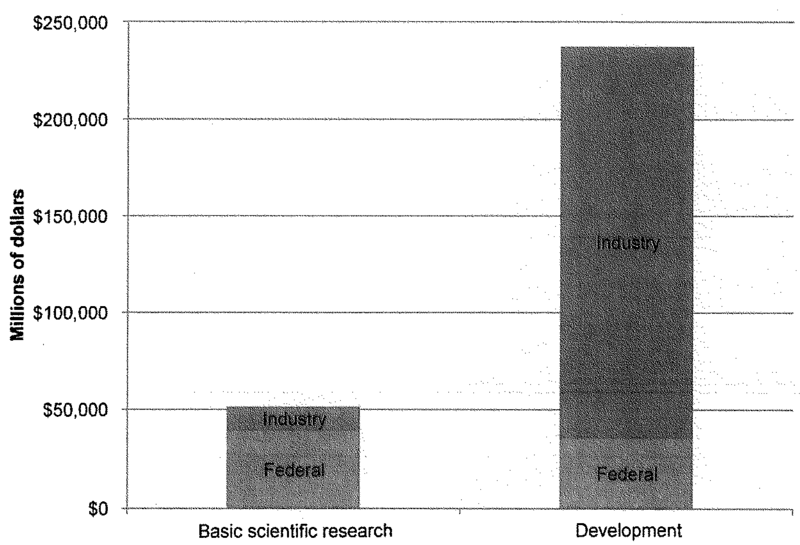
Federally-funded basic research has supported the creation of technological capabilities that impact the lives of Americans every day, such as magnetic resonance imaging, global satellite navigation, lasers, and broadband internet. Though the relationship between federally-funded R&D and technological innovation to the marketplace is complex, businesses that conduct or fund R&D have a much higher rate of innovation than those that do not.[2]

Tomorrow's innovations are expected to further transform the way we live. However, the future of specific technological innovations is particularly difficult to predict, especially how they might be fully utilized and when these innovations will become readily available and used by the American public.

This hearing will explore many science and technology policy issues, including specific recommendations for federal policies that ensure federal R&D innovations continue to drive American economic competitiveness.

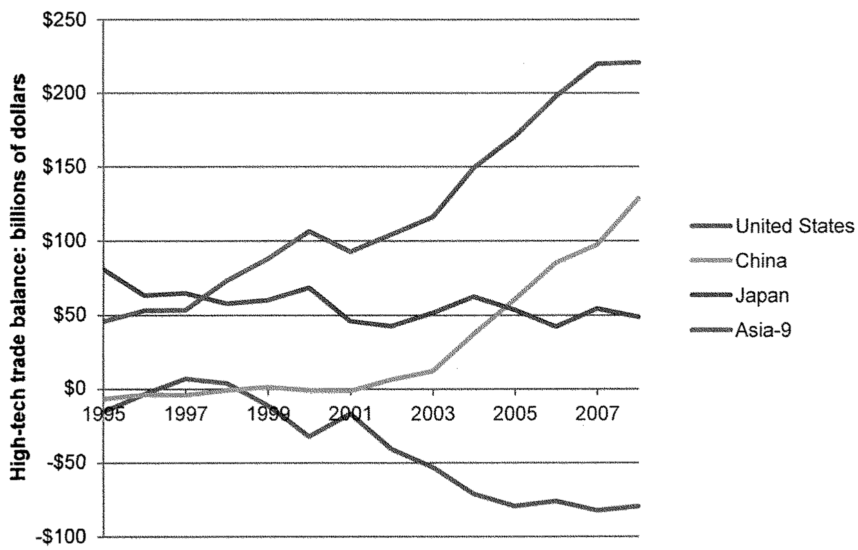
Some useful background information related to U.S. industry and federal R&D spending and U.S. exports and market share for hi-tech products are provided below. More information and context for this background information can be found at these websites: http://www.innovationtaskforce.org/docs/Benchmarks%20-%202012.pdf and http://www.aaas.org/spp/rd/guihist.shtml.

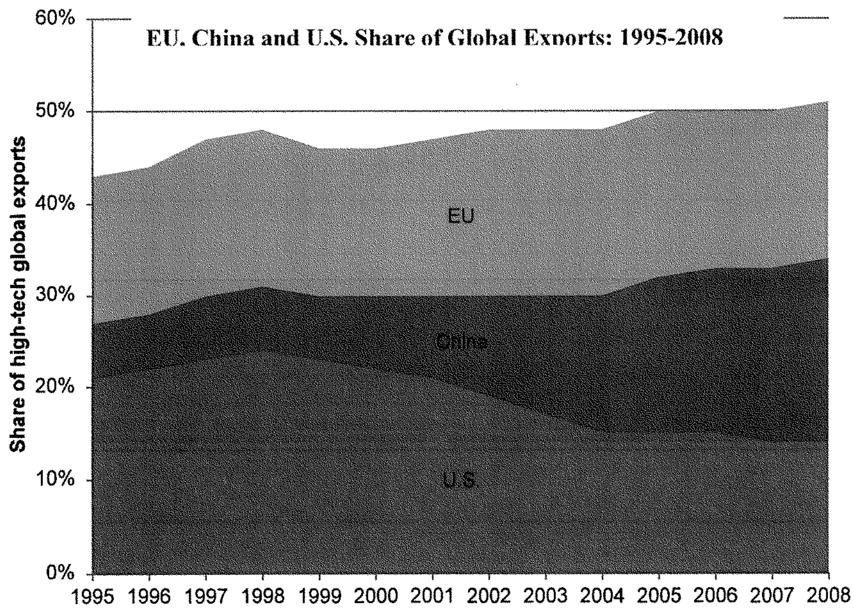
Public and Private Distribution of R&D

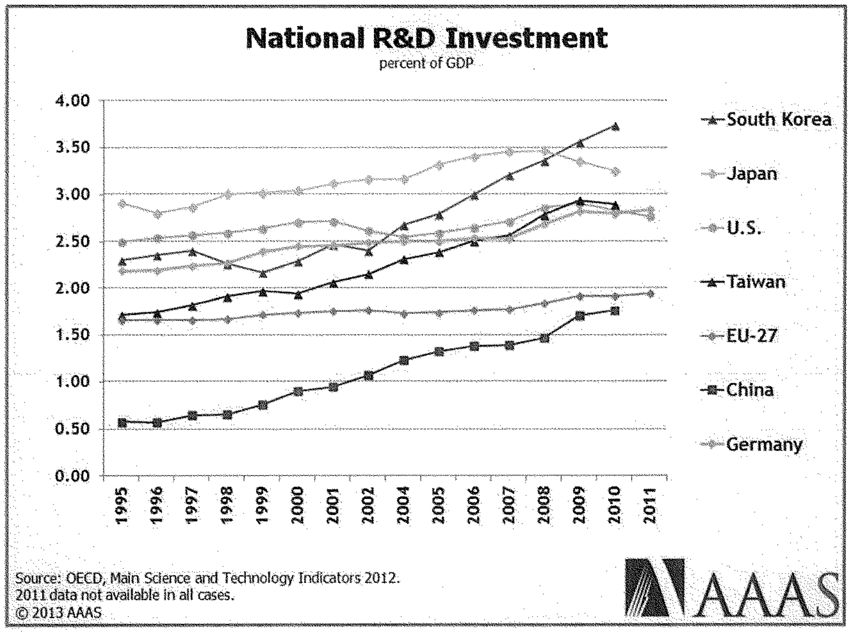


[2]Research, Development, Innovation, and the Science and Engineering Workforce; NSF 2012; http://nsf.gov/nsb/publications/2012/nsb1203.pdf

The High-Tech Trade Balance for Selected Nations






National R&D Investment
percent of GDP
4.00
3.50
3.00
2.50
2.00
1.50
1.00
0.50
0.00
1995
1996
1997
1998
1999
2000
2001
2002
2004
2005
2006
2007
2008
2009
2010
2011
South Korea
Japan
U.S.
Taiwan
EU-27
China
Germany
Source: OECD, Main Science and Technology Indicators 2012.
2011 data not available in all cases.
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Chairman SMITH. The Science, Space, and Technology Committee will come to order. I will recognize myself for an opening statement, then the Ranking Member for her opening statement.

The topic of today's hearing, the first of this Committee in this Congress, is "American Competitiveness: The Role of Research and Development." This is an appropriate hearing because much of the jurisdiction of this Committee relates to keeping America globally competitive.

America's ability to compete depends on whether we have the present vision to conduct the science that will define the future. As the wall behind me says, "Where there is no vision, the people perish"—this Committee's goal, and today's hearing, is to help define that vision and ensure that America continues to be the leader of global innovation.

Our first hearing today will begin this process by examining the positive impact of today's R&D and looking forward to potential breakthrough innovations in the future.

Americans have always been innovators and explorers. Our ancestors crossed oceans, opened frontiers and ventured to explore a new continent and even traveled to the Moon. From the Lewis and Clark Expedition to the International Space Station, from the telegraph to broadband Internet, Americans have led the exploration of the unknown and developed inventions of the future. In our short history we have produced world-famous scientists and inventors like Benjamin Franklin, Thomas Edison and Jonas Salk.

But countless more American scientists who are not world-famous nonetheless have been changing this world. Have you heard of William Burroughs, John Bardeen or Ruth Benerito? According to the National Inventors Hall of Fame, Mr. Burroughs created the electronic calculator. Mr. Bardeen worked with the Nobel prize-winning team that developed the transistor and helped create Silicon Valley in California and Silicon Hills in Austin, Texas. And we can thank chemist Ruth Benerito for developing wrinkle-free cotton, which is in the shirts many Americans wear today, including mine.

But is America as innovative as it used to be? Some wonder if America's greatest technological achievements are behind us, and if other nations like China and India will soon surpass us, or perhaps already have.

Some nations are creating environments so attractive to global manufacturers that companies have relocated much of their activities on foreign soil. Our global trade imbalance is growing as we export less and import more, and today, this imbalance includes many high-tech products. Other nations are changing their policies to become more competitive, and so should we.

Fortunately, blazing trails into new frontiers is what America has always done best. To set the stage for this Congress and to understand where America is heading, we have very knowledgeable witnesses testifying before us today. Each of them thoroughly understands both public and private research and development efforts as well as where our global competitors are headed. Members of this Committee have the opportunity to work together on policies that will help America stay competitive, and today's hearing is a first step.

[The prepared statement of Mr. Smith follows:]

PREPARED STATEMENT OF CHAIRMAN LAMAR SMITH

The topic of today's hearing, the first for this Committee in this Congress, is "American Competitiveness: The Role of Research and Development." This is an appropriate hearing because much of the jurisdiction of this Committee relates to keeping America globally competitive.

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Chairman SMITH. That concludes my opening statement, and the gentlewoman from Texas, Ms. Johnson, is recognized for hers.

Ms. JOHNSON. Thank you very much, Chairman Smith, for holding this hearing, and thank you also for yesterday's bipartisan retreat, which was delightful.

Chairman SMITH. Thank you.

Ms. JOHNSON. I am looking forward to these very distinguished witnesses today and hope that all of us will listen attentively. I know that we will hear from our witnesses about the critical importance of federal research and development investments, and I look forward to their testimony.

As the competition for scarce resources has intensified, there have been some who would describe the research community as just another special interest lobbying group to share the pie. I could not disagree more. They should have special interest and self-interest, and I hope they do, whether they are representing universities or high-tech companies. But to label them as nothing more than another special interest group is, at best, misleading. Without dismissing the value of many other investments we make with our limited discretionary budget, there is probably no single investment we make, other than education, that has done more to ensure our Nation's long-term economic vitality than the investment in R&D.

This holds true for the very long-term investments that the Federal Government is uniquely suited to make in exploratory research where we have no idea what, if any, applications will result. But it also holds true for the financial and intellectual partnerships we build with the private sector to address more mid-term R&D challenges. All of these investments yield immeasurable benefits to our economy and our society in terms of companies built, jobs created, and a society made healthier, safer, and more secure. They also have the secondary benefit of training the next generation of scientists and engineers who will contribute in all of these ways to their own generation, and I am particularly pleased to see a few of them sitting out there I hope will be some of those in the future.

Some specific examples of groundbreaking innovations and companies that would not have been possible without federal R&D investments include the Internet, GPS, Google, the iPhone, and God, what we would do without barcodes? I expect that we will hear more examples from the witnesses, and we could probably spend our entire two hour hearing reading off such a list.

And yet, I fear, some of my colleagues in Congress would still be unimpressed. We will still hear arguments that the Federal Government's role should be restricted to so-called basic research because the private sector can do the rest alone, that everybody has to take a cut, that the 8.2 percent cuts looming on March 1 may hurt a bit but are better for the country in the long run.

I happen to believe personally that we can invest it in unemployment and food stamps or we can invest it in our future that would eliminate the need for both. So let me attempt to briefly preempt some of these arguments. R&D is not a simple, linear process from basic to applied to development and so on to a final commercial product. It also doesn't go in only one direction. R&D is part of a complex innovation process with many feedback loops. There is no clear line at which the public role ends and the private role begins and there has not been in any of our lifetimes. That is why partnerships between the public sector, namely our federal agencies, and the private sector, such as Mr. Templeton's company, Texas Instruments, are so important.

Second, I would like to say a word about the consequences of sequestration. At the risk of repeating myself, we would not just be turning off the lights on many groundbreaking research facilities and experiments today, we would be eating our seed corn for tomorrow. We would know that at the end of the tunnel, the lights are out. What talented young person would see a future in scientific research after sequestration does its damage?

Our witnesses were asked in their testimony to speculate on what kind of breakthrough technologies we might see in the next 5 to 20 years. I think if any of us knew the answer to that, we would really be rich. That is the point. We don't know what directions our research might take, what unknown applications and innovations will be developed, and nor did our predecessors when they invested in what we have today. We cannot afford to overestimate what the private sector is prepared to do on its own, and we cannot afford to underestimate the negative consequences for the Nation's R&D enterprise of letting sequestration go forward.

With that, Mr. Chair, I yield back.

[The prepared statement of Ms. Johnson follows:]

PREPARED STATEMENT OF RANKING MEMBER EDDIE BERNICE JOHNSON

Thank you Chairman Smith for holding this hearing, and thank you to our distinguished witnesses for taking the time to appear before the Committee this morning. I know that we will hear from all of our witnesses about the critical importance of federal research and development investments, and I look forward to your testimony.

As the competition for scarce resources has intensified, there have been some who would describe the research community as just another special interest group lobbying for their share of the pie. I could not disagree more. Yes, they have some self-interest, whether they are representing universities or high-tech companies.

But to label them as nothing more than another special interest group is, at best, misleading. Without dismissing the value of many other investments we make with our limited discretionary budget, there is probably no single investment we make, other than education, that has done more to ensure our nation's long-term economic vitality than our investment in R&D.

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Some specific examples of the groundbreaking innovations and companies that would not have been possible without federal R&D investments include the internet, GPS, Google, the iPhone, and barcodes. I expect we will hear more examples from the witnesses. We could probably spend our entire two-hour hearing reading off such a list.

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What talented young person would see a future in scientific research after sequestration does its damage?

Our witnesses were asked in their testimony to speculate on what kind of breakthrough technologies we might see in the next 5–20 years. I think if any of us knew the answer to that, we'd be rich. That's the point—we don't know what directions our research may take, what unknown applications and innovations will be developed.

We cannot afford to overestimate what the private sector is prepared to do on its own. And we cannot afford to underestimate the negative consequences for the nation's R&D enterprise of letting sequestration go forward.

Chairman SMITH. Thank you, Ms. Johnson.

Let me introduce our witnesses. Our first witness is Mr. Richard Templeton, Chairman, President and CEO of Texas Instruments. Mr. Templeton has served as Texas Instruments' Chairman of the Board since April 2008 and President and Chief Executive Officer since May 2004. In addition to his work with Texas Instruments, Mr. Templeton also serves as the Chair of the Task Force on American Innovation, a broad group of stakeholders that support scientific research. Mr. Templeton earned his B.S. in electrical engineering from Union College in New York.

Our next witness is Dr. Shirley Ann Jackson, President of Rensselaer Polytechnic Institute since 1999. Prior to her tenure, Dr. Jackson served as the Chair of the U.S. Nuclear Regulatory Commission. She also has had an extensive career working in several prestigious physics laboratories researching subatomic parties. Dr. Jackson earned her Ph.D. in theoretical elementary particle physics from MIT.

Our final witness is Dr. Charles Vest, President of the National Academy of Engineering. He was elected to this position in 2007 and is serving a six-year term. Dr. Vest also is the President Emeritus of the Massachusetts Institute of Technology and earned his Ph.D. in mechanical engineering from the University of Michigan. Prior to his time in the academic world, Dr. Vest was Vice Chair of the U.S. Council of Competitiveness for eight years and a member of the President's Committee of Advisors on Science and Technology during the Bush and Clinton Administrations. Both Dr. Vest and Dr. Jackson were also distinguished members of the panel that authored the original 2005 National Academy study *Rising Above the Gathering Storm*. This study recommended ways to keep American economically prosperous.

Before I recognize Mr. Templeton, I just want to call attention to Members on their desk, they should have an op-ed from today's Politico that was written by two of our witnesses today and which is well worth reading. It is called "A Critical Role in Innovation" by Richard Templeton and Shirley Ann Jackson.

Chairman SMITH. Mr. Templeton, we will begin with you.

TESTIMONY OF MR. RICHARD TEMPLETON, PRESIDENT AND CEO, TEXAS INSTRUMENTS

Mr. TEMPLETON. I want to thank Chairman Smith, Ranking Member Johnson and of course all the Members of the Committee for convening this hearing so early in the new Congress on such an important topic. I really am honored to be here today with Dr. Jackson and Dr. Vest, really well-known innovators with great, keen insight into policy.

Over the last 50 years, scientific and technological innovation has been responsible for as much as half of our economic growth. The United States has been a clear net global winner during this time, and while there are a number of factors that can explain that, I actually believe the investments by the Federal Government in basic research at our universities and at our federal labs were a critical factor in determining our success.

I would point out as we think about this topic, this phrase of research and development, or R&D, is used inseparably many times, and I think it is important to point out that inside of research and development, there is something called basic research, and to get a sense of that, it is really something that is done to discover basic principles without necessarily having a commercial purpose in mind. It could take 5 to as much as 15 years for that to pay off, or perhaps never. But when those basic principles are discovered and successful, they can have enormous dividends.

For example, the Space Program and the Defense Department propelled many of the advancements in the semiconductor industry where today U.S.-headquartered firms hold nearly half of the worldwide market and support nearly 250,000 direct jobs. The Internet is another wonderful example.

Basic research requires significant funding from the Federal Government because it can take the long-term view and make the scope of investment needed. This funding goes to universities, not to companies. I offer the Committee four points to consider when you think about research funding.

First, the United States was a clear winner of the first round of the innovation game. We are home, as was noted in the opening comments, to some of those most innovative companies in the world, names like Apple, names like Google, names like Intel, and we of course like the name of Texas Instruments on that list. The United States is the net winner economically because these companies are headquartered here in the United States and they are not headquartered somewhere else. They are here in many ways because the basic research many years ago was done in the United States. We had the best research universities, which in turn attracted the smartest people from around the world to want to go practice at those best institutions.

Second point, that this game is changing in round two. The relative advantages that the United States has had over the last 50 years have significantly weakened. Today we risk that the next generation of these companies will in fact be started up and headquartered somewhere else. So there is really a few simple reasons as to why that could take place. First, other countries have seen the United States playbook and they are very interested in being able to replicate it. They see the benefits that it has yielded and they are busy putting in place programs to provide incentives for companies to try and start in their countries. The second element that has weakened the U.S. position is that federal investment in basic research, in physical sciences and engineering, as a percent of GDP has fallen to less than half the level since 1970. If you contrast that by some very key competitors, key competitors meaning countries like Korea or China, they are actually increasing their R&D in physical sciences as a percent of GDP. Lastly is skills. Our industry works because we have great minds, and there are two issues here. First, our immigration policies do not encourage today the best minds to come to the United States and in fact stay in the United States, and also the best minds have got other choices around the world. In fact, today we educate some of these best minds and then we show them the door to return home. Secondarily is our own K–12 STEM systems are faltering and we have to get that turned around.

The third point that I would like to point out is that the stakes in the next round, the next 50 years, are even higher than they were for the last 50 years. Leadership in nanoelectronics will impact many aspects of our economy: health care, energy, transportation, safety, security and much more. China and Korea understand that the country that leads in nanoelectronics will reap the economic benefits the way the United States has dominated the last 50 years, or the microelectronics era.

Fourth point: I think there are four areas that changes in policies need to be focused to change the outcome. First, the federal funding in basic research. Even in tough economic times, we must protect the investments in the future. Second, we must make a priority for world-class STEM education, that is K–12, in the United States. This needs to be a national imperative, implemented on a local basis. Three, high-skilled immigration reform. I appreciate the leadership that, Mr. Chairman, you have shown, Ms. Lofgren, on the issues, and we look forward, hopefully, to a resolution to that. And then fourth is comprehensive tax reform for U.S. companies to build to compete globally. The world has changed considerably since 1986, the last time taxes were reformed. We must have an environment where U.S.-headquartered companies can compete effectively on a global basis because that is where 95 percent of the world's population is.

So my conclusion, investing in basic research at our universities has been critical to America's success over the past 50 years, and I believe it will be more important going forward, and I am certainly happy to answer any questions.

[The prepared statement of Mr. Templeton follows:]

TEXAS INSTRUMENTS

American Competitiveness: The Role of Research and Development

Testimony before the U.S. House Committee on Science, Space, and Technology

Richard K. Templeton

Chairman, President and CEO

Texas Instruments Incorporated

February 6, 2013

Chairman Smith, Ranking Member Johnson, Members of the Committee – thank you for the opportunity to testify before you today on *American Competitiveness: The Role of Research and Development*. Texas Instruments has enjoyed a close relationship with this committee for many years given our mutual interest in research and STEM education. I applaud your convening this important hearing so early in the Congress.

I am pleased to testify alongside Dr. Charles Vest and Dr. Shirley Ann Jackson, who have each done so much to draw attention to innovation issues. One of TI's founders, Erik Jonsson, graduated from Rensselaer Polytechnic Institute in 1922, illustrating that even many decades ago, great educational institutions trained the entrepreneurs that create entirely new industries.

I have been asked to address the industry perspective on research and development (R&D). I appear on behalf of the Task Force on American Innovation and as a board member of the Semiconductor Industry Association. I will draw heavily on my more than 30 years with Texas Instruments in my testimony.

If I leave you with one message today, it is this: federal funding of fundamental scientific research is critical to our nation's continued competitiveness, economic growth and workforce development. It will shape our future. It will launch new industries, undergird our scientific and engineering infrastructure, produce our next Nobel Laureates, ensure unparalleled academic excellence of our universities, and provide an economic future for the nation. It is not a switch that can be turned on and off.

A fundamental theme will be the critical feedback loop between industry, universities, and government as a key characteristic of the U.S. innovation ecosystem. Innovation is a shared responsibility, and government plays an essential catalytic role in making it happen. Economists attribute as much as half of economic growth over the last fifty years to innovation, scientific, and technological progress – much of which would not have occurred without federal investments in university-based research.

TI is the nation's second largest semiconductor manufacturer with more than 100,000 innovative products to help our 100,000 customers unlock the possibilities of the world as it could be –

smarter, safer, greener, healthier and more fun. We make chips that go into everything from consumer electronics to automobiles, medical devices, motor controls – just about anything with an on and off switch. Innovation has been a cornerstone of our 83-year history. In 2012, TI invested nearly $1.9 billion in R&D, a figure that grew 9 percent compared with 2011, even as our annual revenue fell between the two years. This might seem counterintuitive. However, over the years I have observed that companies that invest during a downturn are better positioned for the recovery.

The same concept applies to countries. If we want the United States to remain the leader in cutting-edge technologies, in knowledge-based industries, and to create the related high-paying jobs and new companies, we must prioritize investment in research.

My testimony today focuses on five areas: 1) types of R&D and funding sources, 2) industry approach to R&D, including model private-public partnerships, 3) global R&D incentives, 4) breakthrough technologies that might be realized, and 5) policy implications.

R&D types and funding sources

The term "R&D" is often used inseparably, but there is an important distinction between research and development. The days of the Bell Labs model of large-scale, corporate-funded exploratory research labs are long gone. Companies invest largely in development, and to a lesser extent in research. Development focuses on executing the next iteration of existing products and new products. This is particularly true in the high-technology sector. Companies must continually innovate or become obsolete.

Research can be further segmented into fundamental (or basic) and applied. Fundamental research is exploratory in nature and conducted to understand basic principles without necessarily having a commercial purpose in mind. The benefits are broad, societal, and potential payoffs are further in the future. Applied research is undertaken with a specific end, an attempt to solve a practical problem in a much nearer term.

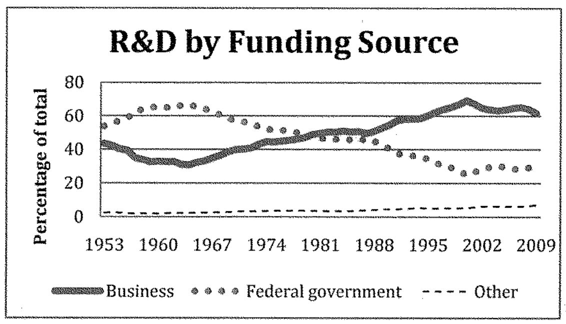
Historically, the federal government has been the primary source of basic research funds and supports higher-risk, exploratory research that universities are best able to conduct. It is basic research upon which all other R&D rests, including that performed by the private sector.

Individual companies or consortia are not able to perform basic research on the scale or sustained level of the federal government. Basic research requires patient capital. It can take 5-15 years or more to bear commercial results, if at all. However, when it does pay off, those payoffs to our society and to our economy are spectacular and many times, in unanticipated or unintended ways. And sometimes the pay back extends for years as researchers find new and innovative applications for these discoveries. If you look at examples of federally funded basic research outcomes – the laser, GPS, the Internet, and semiconductor advances – all have revolutionized the world and how we interact with it. The fundamental research undertaken on these technologies began 50 to 60 years ago.

The private sector, on the other hand, generally focuses on later stage research and development. As the Congressional Joint Economic Committee has stated, "Despite its value to society as a whole, basic research is underfunded by private firms precisely because it is performed with no specific commercial applications in mind."

Industry invests some $270 billion in R&D, but it focuses mainly on the "D" – the development of technologies that can be brought to use and markets in the near term. While it is essential to the innovation process, the long-term horizon of most scientific research conducted at universities, which perform a majority of basic research, is viewed by industry as too risky for significant private sector investment. This is why the federal government's support for basic scientific research is critical to innovation.

In the United States, expenditures in R&D have largely remained stagnant for the last 30 years as measured as a percent of GDP. U.S. national R&D from all funding sources was $400.5 billion in 2009, just shy of 3 percent of GDP. While the share of federal investment in R&D has declined, the private sector share has increased, which has maintained the ratio to GDP, but pulled activity toward the applied and development side of the continuum.



Source: National Science Foundation, *Science and Engineering Indicators, 2012*, Fig 04-05

National investment (all sources) in basic research was $76 billion in 2009 (0.53 percent of GDP), illustrating that resources are mostly focused on applied research or development. The federal government represented 53 percent of basic research investment, while industry funded 22 percent of the total. University-performed basic research was $40.6 billion (0.28 percent of GDP), and of this, the federal government funded $24.2 billion (0.17 percent of GDP).[1]

Industry approach to R&D

Research is an essential element of any knowledge-based company. In the semiconductor industry, we have learned from experience to manage through challenging times. Few sectors are as cyclical as ours with great highs and very difficult lows. Yet, the semiconductor industry consistently invests nearly the same percentage of sales in R&D, even as sales growth has fluctuated. In 2011, U.S. semiconductor companies invested $27 billion in R&D, or 18 percent of sales.

How TI invests in R&D
TI's R&D work runs the gamut from basic research, undertaken in collaboration with others in the industry, to more near-term applied research and development.

Nearer term research is embedded in business units throughout the company, enabling widespread access to innovative ideas that benefit TI customers, and allowing R&D staff to quickly gauge customer reaction to new ideas. TI also has additional R&D teams focused on broad areas of important technology, and around particularly promising applications.

In 2008, on the 50^{th} anniversary of the invention of the integrated circuit, TI established Kilby Labs as a center of innovation at three sites within the company to inspire creative ideas for breakthrough technologies. The lab allows selected TI researchers to work full time on a high-risk, high-reward project for several months to a year. Engineers assigned to those Kilby projects then return to their business units. Areas being explored today include energy management, medical and health care, cloud computing (and related infrastructure), and safety and security.

The scope of projects is virtually unlimited within TI's fields of interest and expertise, and they have ranged from terahertz clock sources to micromachines. TI often engages with university professors on these efforts. Kilby Labs are also a magnet for top students from around the world, some of whom start as summer interns and then join TI after graduation. Student interns work with TI staff on projects, gain insight into how TI operates and at the same time further their graduate studies. Interns have come to work at Kilby Labs from universities near and far, including are the University of Texas, MIT, Texas A&M, Stanford, Columbia, Georgia Tech, Rensselaer, UC Berkeley, UCLA, the University of Illinois, the University of Wisconsin and Cambridge University.

Public-private partnerships: semiconductor industry examples
TI's basic research investments are almost always in collaboration with others to tackle fundamental technical challenges that no company or university can solve alone. The semiconductor industry has a wonderful tradition of supporting pre-competitive, collaborative research that dates back to the 1980s and which has evolved as the industry's needs and challenges have changed.

For example, the Semiconductor Research Corporation (SRC), founded in 1982, is a consortium of semiconductor companies that collaboratively funds pre-competitive university research in semiconductor technology and design. TI has been a member of SRC almost since its inception, contributing financial and human resources to maximize the impact and the value of the consortium.

Over the past five years, SRC has administered $215 million in industry funding for university research, supporting more than 1,500 students annually. These industry dollars are matched or leveraged by federal, state and other sources of funds. SRC's consortium model facilitates interaction between industry and government, allowing for co-investment in basic research with various federal agencies, including the National Science Foundation (NSF), National Institute of Standards and Technology (NIST), and Defense Advanced Research Projects Agency (DARPA). U.S. universities represent 97 percent of the investments that SRC makes.

Three SRC-administered programs – The Texas Analog Center of Excellence (TxACE), the Semiconductor Technology Advanced Research network (STARnet) and Nanoelectronics Research Initiative (NRI) – illustrate the pre-competitive research continuum, from nearest to longest term.

TxACE: Through SRC, TI led an effort to establish a collaboration center at the University of Texas-Dallas that focuses on research in analog and radio frequency technologies to address challenges in such areas as energy efficiency, health care, and public safety, which are uniquely reliant on analog technology. The center involves 29 universities, in Texas and outside the state. Total funding for the center is $31.8 million over six years, of which TI and the SRC are providing a combined $15.9 million, and the State of Texas, through the university system and Emerging Technology Fund is providing the remainder. This collaboration of academia, industry, and government is an excellent example of how regional innovation is created.

STARnet: Funded jointly by industry and the Defense Advanced Research Projects Agency (DARPA), the new Semiconductor Technology Advanced Research Network (STARnet) program will allocate a total of $194 million over the next five years to 39 universities across the country for leading-edge semiconductor research, concentrated along six thematic areas focused on extending and moving beyond the current CMOS technology (http://www.src.org/program/starnet/). STARnet is the successor to the Focus Center Research Program, also funded jointly by DARPA and industry in 1997–2012.

NRI: NRI looks even farther into the future, supporting discovery-oriented research that is focused on finding the next technology that will allow the industry to continue to increase performance and decrease cost. Initiated in 2005 by five semiconductor companies, NRI has been recognized by the President's Council of Advisors on Science and Technology and others as a model collaboration that leverages funding and expertise from industry, NSF, and NIST, as well as contributions from state and even local governments. Since the program's inception, industry has contributed $17 million, NSF $20 million, and NIST $12 million.

Why does investment in nanoelectronics research matter? Nanoelectronics is a game-changer for the industry and the country – a disruptive technology that could alter the dynamic of market leadership. The current chip technology, which has been used for four decades, is predicted to reach its scaling and power dissipation limits by 2020. Nanoelectronics holds the promise of a successor technology. The country that discovers this breakthrough research is likely to reap the related economic benefits. The U.S. federal government's research resources, specifically the NSF and NIST are critical to this effort. We appreciate the support that this committee has provided to this effort.

What is important to point out is that in all points along the R&D continuum, industry has skin in the game.

Global competition

Sustained funding of scientific research is required to maintain U.S. leadership and competitiveness. Numerous benchmarks used to measure our nation's innovation efforts, such as the numbers of scientific and engineering degrees awarded, scientific papers and patents produced, and total research investments, indicate that other regions and nations, particularly China and the other rapidly developing economies of Asia, are vigorously investing in science and technology in hopes that they can eventually surpass the United States in key scientific fields.

The United States was once the leader in research intensity, or R&D as a percentage of GDP; it now ranks 8th according to the OECD. U.S. share of global R&D spending is slipping, from 39 percent in 1999 to 34.4 percent in 2010. While U.S. R&D spending has risen on average 3.2 percent, other countries are accelerating their investment – South Korea at 8 percent and China at 20 percent.[2]

For my own industry – which remains the global leader and has on average been the top U.S. export over the last decade – this trend is disturbing. Although the industry has its roots in American innovation, our leadership cannot be taken for granted. Other countries want to attract this industry and many have specifically identified semiconductors in national development plans, establishing aggressive incentives to encourage semiconductor design, manufacturing and R&D. They see the benefits that result from a robust chip industry in terms of both economic activity as well as increased innovation. They are building talent, pouring resources into R&D, and in some cases trying to develop national champions with policies that favor domestic companies and create unique technical standards to force technology transfer.

A quick read of China's 12th five-year plan identifies seven emerging industries in which it hopes to become world-class competitors, including energy-efficiency and environmental protection, next generation information technology, bio-technology, advanced equipment manufacturing, new energy, new materials and new-energy vehicles. All are very innovation-driven, R&D intensive sectors. And China is making the investments. This is a challenge we need to address.

R&D incentives have become a highly popular way for countries to attract and develop their research base. Most of these are tax based. The United States once had the most competitive R&D tax credit. But according to the Information Technology Innovation Foundation, we now rank 24th of 42 countries, and because our credit is temporary it undercuts the very incentive it is supposed to provide. We welcomed the recent extension of the R&D tax credit, yet it is very difficult for companies to plan, or even prepare financial reports, when it is continually renewed retroactively or at the eleventh hour.

In addition to the R&D incentives, all our competitor countries have lower overall corporate tax rates, and many offer special incentives to specific industries such as tax holidays or reduced tax rates for semiconductor companies. A combination of these incentives can in some cases allow a company to operate up to 10 years virtually tax-free.[3]

Breakthrough technologies: semiconductors

History

I want to reiterate the game-changing implications of research by looking a bit to the past but also projecting out to the future. When Jack Kilby invented the integrated circuit at TI, NASA and the Defense Department were some of the first supporters. Federal funding was critical to development of semiconductor manufacturing technologies in the 1960s and 1970s.

The invention of the integrated circuit has propelled space travel, enhanced national security, revolutionized computing and communications, created safer cars and energy-efficient appliances, and improved health care technology. Today, semiconductors represent a $300 billion worldwide market, enable the more than $1 trillion global electronics market, and drive productivity in every sector of the economy. The industry has delivered a 10-fold drop in cost every six years. Investment in R&D is what makes this possible.

An example of a TI product that can trace its roots to federal research is Digital Light Processing (DLP®) technology, which is a digital mirror device. DLP® has its origins in DARPA projects from the 1970s to improve aircraft cockpit displays. The first commercial use TI found for the technology was for airline ticket printing. In 1989, DARPA funded a program to spur development of high-definition TV industry, which resulted in TI developing the first prototype digital mirror device. Now DLP® is an amazing imaging technology that uses millions of tiny, rapidly-moving mirrors moving thousands of times per second to generate up to 35 trillion colors. DLP® is used in nearly half of the world's projectors, including the handheld Pico, 3D television and movies, and revolutionary medical imaging. TI worked with the University of Texas-Arlington on some exciting research resulting in medical technology that uses DLP® for hyperspectral imaging, which uses electromagnetic spectrum bands to image beyond what the human eye can see, and has applications for non-invasive diagnoses. DLP® applications are being developed for 3D biometrics and there are numerous other projects underway. For TI, DLP® now generates about 6 percent of our revenue and supports hundreds of employees, most in the United States. Perhaps even more importantly, it also supports over 300 companies that are using our technology to create new applications for medical, automotive, and industrial sectors, illustrating that as technology becomes pervasive, it strengthens the broader economy as a byproduct.

Looking ahead

But that's just the beginning. What semiconductors made possible for the information technology industry will now revolutionize health care, security, energy, and transportation.

Bioengineering, at the intersection of medicine and engineering, is an incredibly exciting area. Research has helped develop retinal implants that will allow the blind to see, bionic prostheses, and wireless body sensor patient monitoring.

Other research-based technologies on the horizon include 3D biometrics, video analytics, perpetual devices (powered by ambient light, heat, or vibration), intelligent driverless cars, and wearable electronic devices (clothing, fingertips, and glasses). Emerging infrastructure and applications such as smart grid/energy management, cloud computing, data analytics, and the Internet of Things are driving new innovations. The possibilities are limitless. And research remains at the heart of making it all work.

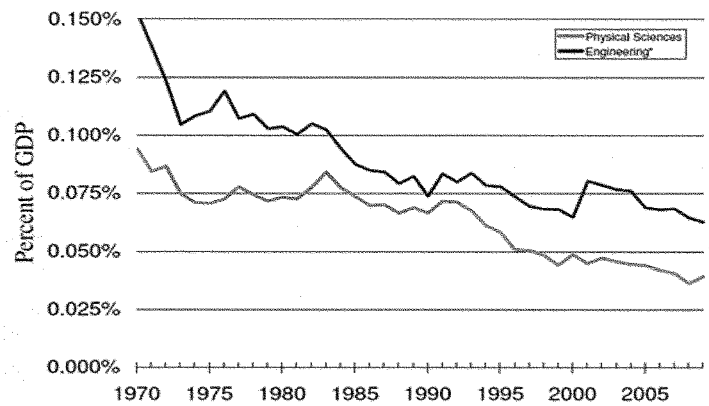
Policy Implications

Prioritizing research investment

The physical sciences and engineering are integral disciplines to the semiconductor industry and many others. Federal investment in these fields has declined as a percentage of GDP over the last four decades.

The key agencies funding physical science and engineering research are the National Science Foundation (NSF), National Institute of Standards and Technology (NIST), Department of Defense, Department of Energy Office of Science, and National Aeronautics and Space Administration (NASA).

Federal Funding of Research in Physical Sciences and Engineering



Source: Task Force on American Innovation

As the continuing resolution expires in March, I urge you to provide predictable and sustained funding for scientific research at these key agencies. Boom and bust funding cycles for scientific research hamper scientific progress and discourage students from pursuing scientific and technical careers that are critical to maintaining U.S. scientific leadership. Worse yet, those doing research here in the United States will increasingly consider lucrative offers to continue their research overseas, where the funding stream is more constant and dependable. When research moves out of the United States, the high skilled talent, the intellectual property and possible spinoff companies and corresponding jobs all leave with them.

Building and retaining talent
Research funding is one of the best tools we have to encourage graduate students in STEM fields. The federal investment in scientific research is essential to producing the next generation of scientists and engineers. Thousands of graduate students and post-doctorates, as well as undergraduates, obtain their most important laboratory experience in projects funded by federal research grants. The American system of combining research with training of young scientists and engineers has been enormously successful, and it would be impossible without federal funding.

In the case of public-private partnerships, these graduate students have excellent opportunities to interact with both academia and industry, paving the way for transition to either sector. Through its history, SRC has supported over 7,000 students as part of its unique collaborative research model. Of the SRC-supported students, most graduates have joined sponsoring companies or university faculties, or have continued on to pursue a higher degree. The opportunities graduate students are provided through research funding offer invaluable training for the future workforce of innovative industries and technical drivers of start-up companies.

A major regulatory challenge to research is the U.S. immigration system. Foreign nationals earn 55 percent of the masters' degrees and 63 percent of the PhDs in electrical engineering from our own U.S. universities. Yet these individuals face waits for permanent resident status (green card) lasting several years up to a decade, keeping professional and personal lives in limbo. We need to fix the high skilled immigration system to enable these highly educated professionals to remain in the United States. We are grateful for the leadership that you, Mr. Chairman, and Congresswoman Lofgren in particular have provided in this area. We encourage the Congress to address immigration reform this year. We are pleased that so many bipartisan discussions and initiatives are being developed on this front.

STEM education

Business and government must work together to build the pipeline of STEM students through initiatives that improve math and science proficiency, enhance teaching effectiveness, and ensure accountability. There is a skills gap in this country – for every unemployed person in the United States, there are two STEM job postings. The gap will only widen if we don't engage now to address STEM education at the elementary and high school levels. In 2011, only 45 percent of U.S. high school graduates were ready for college work in math and only 30 percent were ready in science. We also need to engage underrepresented groups in STEM – women, African Americans, and Hispanics. In particular, I'd like to recognize Ranking Member Johnson for her work over the years to address this issue. Creating policies and practices that foster STEM will eventually bring greater equilibrium between job seekers and job opportunities, and in the process strengthen U.S. competitiveness.

TI supports a number of programs designed to encourage student interest and achievement in STEM fields. In addition, TI actively promotes educational excellence with federal, state, and local governments. TI is an active member of Change the Equation, a U.S. private-sector organization of more than 100 chief executive officers focused on improving math and science education by scaling proven practices.

Tax policy

TI supports the efforts to enact comprehensive tax reform to make the United States more globally competitive. Corporate reform should fully contemplate the global nature of business. The worldwide marketplace is complex and highly competitive. We want to be sure that U.S. companies can compete effectively and that the United States becomes a highly attractive location in which to invest. Specifically, our industry seeks to align the U.S. tax system with those our global competitors enjoy by reducing the corporate tax rate, adopting a market-based tax system, and enacting permanent, robust incentives for research and innovation competitive with other countries.

Conclusion
As political leaders, you are facing some tough budget decisions in a challenging economic environment. I urge you to approach this challenge in a thoughtful, strategic way, allocating scarce funds in a manner that gives us the best chance to create economic growth and security both now and in the future. The semiconductor industry may be a useful example to demonstrate how prioritizing investment in research and establishing collaborations that leverage federal participation are an effective and workable model of engagement. Good times or bad, you must manage for the future. Innovation is the pathway there.

Federal funding of scientific research fuels the new ideas and technologies on which our economy, our health, and our national security depend. Predictable and sustained investments in scientific research funding is essential to our efforts to address many of the fundamental issues our society faces, such as energy, national security, and the continuing search for new life-saving medical technologies, vaccines and cures for diseases.

If we want the United States to remain the leader in cutting-edge technologies and knowledge-based industries, both government and industry must support science and engineering research. Investing in research means investing in our universities, in great ideas, and in talented people. It means investing in America.

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[1] *Science and Engineering Indicators*, National Science Foundation, 2012. GDP percentages calculated.
[2] *Rising to the Challenge: U.S. Innovation Policy for Global Economy,* National Academies Press, 2012.
[3] *Maintaining America's Competitive Edge*, Dewey and LeBoeuf study for the Semiconductor Industry Association, March 2009.

Chairman SMITH. Thank you, Mr. Templeton.
Dr. Jackson.

TESTIMONY OF DR. SHIRLEY ANN JACKSON, PRESIDENT, RENSSELAER POLYTECHNIC INSTITUTE

Dr. JACKSON. Chairman Smith, Ranking Member Johnson, distinguished Members of the Committee, thank you for the opportunity to testify before you on American competitiveness, the role of research and development.

I have to say that Rensselaer Polytechnic Institute graduates have been an integral part of America's promise through discovery and innovation since the university was founded in 1824. More importantly, America's health, prosperity, security and global leadership depend upon our strength, as you have heard, in science and technology. Our investments in scientific research and education have made a difference in people's lives. Let me illustrate.

The *New York Times* reported that in October 2004, in Afghanistan, a mortar severely injured a U.S. Marine corporal, Isaias Hernandez. He is an example of so many of our wounded warriors. Shrapnel tore away 70 percent of the muscle in his thigh and fractured his femur. He endured four years of surgeries and physical therapy to little effect until Dr. Stephen Badylak of the McGowan Institute of Regenerative Medicine at the University of Pittsburgh implanted in the corporal's thigh a new gel-based therapy called the extracellular matrix derived from pig bladders. After about 6 weeks, the implanted mixture spurred the growth of muscle tissue, tendons and vasculature and restored physical strength. This work is part of a government-supported regenerative medicine research program at Pittsburgh.

Now, this and much more is the kind of work that faculty and students at Rensselaer do, at MIT do, understanding the role of the extracellular matrix in cell signaling and tissue regeneration, developing enzyme-based coatings that kill antibiotic-resistant bacteria on contact, bioengineering synthetic heparin, all dependent upon federal support of research across the life and physical sciences, chemical and biological engineering, industrial engineering, nanotechnology and data analytics. Life-changing, job-creating, security-sustaining, scientific discoveries and technological innovations have rested on strong collaboration among business, government and academia. This three-way partnership has created an innovation ecosystem that has driven our economy, prosperity and well-being for decades.

Federal investments in scientific research and development built the foundations for a broad range of industries. Many leading U.S.-based global companies including Texas Instruments, Genentech, Google and Cisco Systems all trace their roots to federal research investments.

As you have heard, China, India and other nations are emulating our model by making concomitant investments to gain the benefits we enjoy. If we are to remain globally competitive, we must sustain and enhance the U.S. innovation ecosystem. This requires four things: first, strategic focus to choose important and promising areas to explore and develop and match them to the talent, resources and opportunities we have or can attract; second, game-changing idea generation that arises out of basic research that pushes the boundaries of human knowledge; third, translational pathways that bring discoveries into commercial or societal use; fourth—capital, financial, infrastructural and human capital to support the development and exploitation of promising new technologies.

We need a new financial model for technology-based startups that overcomes the so-called valley of death. We need tax reform. We need physical capital including shared infrastructure, which allows new technologies to be improved and scaled for the marketplace. For example, the Computational Center for Nanotechnology Innovations, a joint effort of IBM, New York State and Rensselaer, holds one of the world's most powerful university-based supercomputers, used for research by our faculty and students and by companies of all sizes to perform research and development and to tap the expertise of Rensselaer scientists and engineers. We must draw more young Americans into STEM fields. We must improve science and mathematics education for all of our children. Retaining high-caliber talent from abroad is important, especially those obtaining advanced degrees in science and engineering from American universities. Advanced manufacturing requires that we make comprehensive education and retraining a priority.

Now, we remain the world leader in scientific discovery and technological innovation but the health of our innovation ecosystem is in jeopardy. As the Congress debates funding for research in these austere times, we know that there are significant challenges, but the nations that invest in research, educate the next generations and make commitments to build effective innovation ecosystems will be the global leaders of tomorrow.

Thank you, Mr. Chairman. I look forward to your questions.

[The prepared statement of Dr. Jackson follows:]

President's Remarks to
U.S. House of Representatives Science, Space, and Technology Committee
Presented by
Shirley Ann Jackson, Ph.D.
President, Rensselaer Polytechnic Institute
Washington, DC
Wednesday, February 6, 2013

Thank you, Mr. Chairman, Ranking Member, distinguished Members of the Committee. It is a pleasure to be here today to talk to you about the status of the research and development enterprise in the United States.

I am President of the nation's oldest private technological research university, Rensselaer Polytechnic Institute. Our graduates have been an integral part of America's promise, through discovery and innovation, since the university was founded in 1824. America's health and prosperity, our security, and the availability of good jobs depend upon our leadership in science and technology. As a nation, we have invested in education and scientific research. These investments have made a difference in people's lives.

Let me illustrate **how** with a true-life **story.** The New York Times reported that, in October 2004 in Afghanistan, a mortar exploded, and a US Marine Corporal (Isaias Hernandez) was nearly ripped apart by shrapnel, which tore away seventy percent of the muscle in his right thigh, and fractured his femur. Corporal Hernandez endured four years of surgeries and physical therapy – to little affect; **until** he met a doctor (Stephen Badylak) of the McGowan Institute of Regenerative Medicine at the University of Pittsburgh, who cut open (once again) the Corporal's thigh, and applied what is known as the **extracellular matrix** – derived from pig bladders.

The **extracellular matrix** fills the space around the body's cells. It contains hormones, structural proteins, and other molecules that maintain cell function and health, mediate inter-cellular communication, and, importantly, guide tissue growth. **Miraculously**, after about six weeks, the implanted gel mixture spurred the growth of muscle tissue, tendons, and vasculature, and, with it, restored physical strength to the marine's thigh.

Dr. Badylak does **not** really know how the extracellular matrix works. But, what **is** known is this: it becomes part of the **existing** tissue, it draws **stem cells** to the implant location, it changes the body's immune response from **rejection** to **reconstruction**. By recruiting the body's **own** stem cells and putting them to work, the extracellular matrix **obviates** the need for controversial and difficult stem cell implants. Think of it as a kind of biological **catalyst**. The work I have described is part of a ($70 million) government-supported regenerative medicine research program.

This is the kind of work that researchers at Rensselaer are engaged in – deriving breakthroughs in the use of **adult** stem cells, understanding the role of the **extracellular matrix** in cell signaling and tissue regeneration, developing **enzyme-based** coatings that kill antibiotic-resistant bacteria (MRSA) on contact, bioengineering **synthetic heparin**, and much more.

Heparin-like molecules are key components of the extracellular matrix, serving to mediate the exquisite control of signals that enables the extracellular matrix to serve as a highly tuned niche for cell function.

Interestingly, heparin also serves as the most widely used intravenous anticoagulant drug with more than 100 tons produced annually worldwide. Heparin was discovered in 1916 and entered early clinical trials as the first "biologic" drug during the 1930s, before the establishment of US Food and Drug Administration. Heparin is produced today much like in the early years of the last century. The raw material is isolated from pig intestines in a large number of small factories in countries with little quality control.

This largely unregulated raw heparin is then converted into the actual drug within well-controlled and regulated processing facilities here in the U.S. Nevertheless, this lack of regulation opened the door for the purposeful contamination of several raw heparin batches, which resulted in the purified drug also being contaminated, and further resulting in nearly **100 deaths** in the U.S. This contamination served as a wake-up call to the pharmaceutical industry and the FDA, as well as other regulatory agencies worldwide, which led to a major multidisciplinary effort, spearheaded by **Robert Linhardt at Rensselaer Polytechnic Institute**, to develop a non-animal sourced, **bioengineered heparin.**

The large-scale production of **bioengineered heparin** involves the use of enzymes, nature's catalysts, which place key chemical moieties onto the heparin backbone, thereby endowing the molecule with its well-known anticoagulant properties. By immobilizing (or attaching) these enzymes onto finely tuned materials, these enzymes are stabilized to enable economically viable, large-scale production of bioengineered heparin. While heparin is medically important, bioengineered heparin is built on the intersection of chemistry, biology, materials science, and data and computational science largely supported by the National Science Foundation and the various agencies within the Department of Defense.

Immobilized enzymes have other uses too, including those that can impact long-term space missions. Nature uses enzymes in many ways, including protection from pathogens. An enzyme in our tears, lysozyme, acts as a disinfectant by killing bacteria that enter the eye. Similarly, some bacteria produce enzymes that kill other bacteria that encroach on their environment. By putting these enzymes into surface coatings, researchers at Rensselaer Polytechnic Institute led by **Jonathan Dordick** have developed a paint that kills **methicillin-resistant *Staphylococcus aureus* (MRSA)** on contact, yet does not harm human cells.

In fact, this **enzyme-containing paint** was used on the final mission of the **Space Shuttle Atlantis** and was just as effective in space as here on earth. This has important implications for long-term space flights, whether on the **International Space Station** or a **mission to Mars**, where pathogen-free environments are critical to the health and well being of the crew.

The extracellular matrix-based therapy described, as well as the bioengineered heparin breakthrough, comes not just from one discipline, but from research results based in the life sciences, chemical and biological engineering, nanotechnology and materials science, industrial engineering, space science, and earth and environmental sciences. So, once again, the confluence of fundamental science and real-world applications is built on the shoulders of federal funding of basic and applied research.

We already are seeing how genomics, transplanted organs and limbs, artificial organs, embedded sensors, and expert systems are transforming medical care and treatment. Undoubtedly, there will be **even more breakthroughs** that will surprise us, and continue to change lives.

An **important** point is that these breakthroughs come from a **spectrum** of basic research funded by the federal government – across a broad disciplinary front **and** at the intersection of disciplines.

Life changing, job creating, security sustaining scientific discoveries and technological innovations in the United States have long been driven by a strong collaboration among business, government, and academe. This three-way partnership has created an "innovation ecosystem" that has driven our economy, our prosperity, and our well being for decades.

Federal investments in scientific research and development built the **foundations f**or a broad range of industries such as information technology, communications, and advanced materials. Many leading U.S.-based global companies including **Genentech, Google, and Cisco Systems** all can trace their roots to federal research investments.

> The roots of **Genentech** lie in breakthroughs from government supported research that led to the discovery of DNA and the ability to manipulate it.
>
> **Google's** business rides on the backbone of the **Internet**, the Global Positioning Satellite System **(GPS),** and breakthroughs in computer science – all derived from research and infra-structure supported or built by the Federal government, often for mission driven purposes, but later opened up for commercial use.
>
> **Cisco**, likewise, has benefitted from government sponsored research and infrastructure.

Along with the research support was linked federal support for the people -- the scientists and engineers who did the work – often, including students.

The successes of the innovation ecosystem in the United States have not gone unnoticed. China, India, and other nations have studied our approaches to collaborative support – including government support – for education, research, and development, and they are emulating our model by making concomitant investments so they can gain the same benefits for their citizens. If the U.S. is to remain globally competitive, we must sustain and enhance the U.S. innovation ecosystem. We must be positioned to apply science to address the key global challenges of access to clean water, food security, energy security, health security, and disease mitigation, and the corresponding risks of climate change and resource allocation. Research in the areas of nanotechnology, big data, biotechnology, and smart systems hold great promise for producing new products and processes and changing our lives.

But what is the **special brew** that will help us to strengthen the U.S. innovation ecosystem? Our system rests on the three-legged stool of industry, academia, and government, and collaboration among them. Each sector has its role to play, and each must participate effectively and cooperatively.

An innovation ecosystem requires four things:

First is **strategic focus**. Among a world of possibilities, we must choose important and promising areas to explore and develop, and these must match the talent, resources, and opportunities we have or can attract.

Second is **idea generation**. Game-changing ideas tend to arise out of basic research, which pushes the boundaries of human knowledge. Universities are critical players here, because basic research dovetails magnificently with our educational mission.

The **third** element requires **translational pathways** that bring discoveries into commercial, or societal, use. The protection, regulation, and exploitation of intellectual property are the front-end of translation. Support for start-ups, business incubators, specialized industry collaborations, and public/private partnerships are all key in this process.

The **fourth element** of a robust innovation ecosystem is the **financial, infrastructural, and human capital** to support the development and exploitation of promising new technologies.

We clearly need a new financial model that can overcome the so-called "valley of death," for entrepreneurial, technology-based start-ups -- between venture funding and full-blown major investment -- when no financing is obtainable.

Equally important is the **physical capital** that allows new technologies to be improved and scaled for the marketplace — facilities for applied research – including shared infrastructure -- for the prototyping and testing of new technologies, for the development of advanced manufacturing processes for modeling and simulation.

Good examples exist. The **Computational Center for Nanotechnology Innovations (CCNI)** is a joint project of **IBM**, **New York State**, and **Rensselaer**. It not only hosts one of the world's most powerful university-based supercomputers, used for research by our faculty, it also allows companies of all sizes to perform research, and to tap the expertise of Rensselaer scientists. The **CCNI** has **800** discrete users, and **25** corporate partners.

The **most crucial** of capital required for our ecosystem is **human capital**.

We must draw more young Americans into science, technology, engineering and mathematics, and educate them well. We must address what I have called the the "Quiet Crisis" of a looming loss of STEM talent due to pending and actual retirements of today's scientists and engineers , without enough young people in the pipeline being prepared to enter these fields. We must improve mathematics and science education from the very beginning of our children's educational careers. And, if we want to remain competitive, we must sustain our commitment to these students throughout their academic careers. Retaining high caliber talent from abroad is equally important, especially those obtaining advanced degrees in science and engineering from American universities.

Clearly, the skilled labor demands of advanced manufacturing require that we make comprehensive education and retraining efforts a priority if the U.S. is to remain competitive.

Retaining technological leadership is not a given. We still experience the benefits of our system, but, as many recent reports have pointed out, its health is in decline. Perhaps most pressing for you, as Members of the Congress, funding for research in these austere times is facing significant challenges.

Those nations that educate the next generations, invest in research, and make commitments to building effective innovation ecosystems are poised to become the global leaders of tomorrow. There should be no disagreement about the wisdom of educating our children in science and technology, without compromise. And our commitment, in terms of investment, rhetoric, and vision should be unmistakable and unshakable.

Mr. Chairman, thank you for the opportunity to submit this testimony today.

Chairman SMITH. Thank you, Dr. Jackson.
Dr. Vest.

TESTIMONY OF DR. CHARLES VEST, PRESIDENT, NATIONAL ACADEMY OF ENGINEERING

Dr. VEST. Chairman Smith, Ranking Member Johnson, honorable Members, it is a privilege to be here today.

Today, the process of R&D that we have been discussing moves new scientific knowledge and new technology developments to marketed products and services at an ever-accelerating speed. It is an increasingly complicated process. It is a globalized process that is at once both highly competitive and cooperative, and it is a process driven by basic research—and one that would ultimately die without basic research.

Some examples of 20th-century innovations that all began primarily with university research include computers, lasers, the Internet, the deployment of the Worldwide Web, the basics of the GPS system, numerically controlled machining for manufacturing, the genomic revolution and most of modern medicine. I contend that there is not a job in America today that does not depend directly on one or more of just these six examples.

Now, predictions of future technologies are very difficult. When I graduated from undergraduate school at West Virginia University as a mechanical engineer in 1963, none of us talked about going into the information technology industry because the IT industry did not exist, but our generation invented it and it became the dominant source of employment for engineers in the intervening years. So I am a true believer that if we invest well in basic research and education, we undoubtedly will be surprised by what the new innovations are that actually arise.

Let me say three barriers to continued success of our wonderful American innovation system. Our K–12 system is failing far too many of our young people. Our current federal policies, as has been said, make it difficult for brilliant foreign graduate students to stay on in the United States yet such immigrants from the recent decades have contributed hugely as professors and especially as entrepreneurs to our system. And our federal R&D tax credit, among other things, needs to be made permanent.

I was asked to comment on National Academy's reports, and I want to cite three that are particularly relevant to the topic of this hearing. I start with our 2005 baseline report, *Rising Above the Gathering Storm*, and thank this Committee for supporting the authorization, passage and reauthorization of the *America COMPETES Act* that is largely based on it. Our findings and recommendations in *Rising Above the Gathering Storm* are as relevant today as they were when they were drafted, and indeed, you heard that from Mr. Templeton. This report offered four broad recommendations, each backed by specific evidence and 20 specific action items, but the big-picture items were four: move K–12 STEM education in the U.S. to a leading position by global standards, double federal investments in basic research in physical sciences and engineering over seven years, encourage more U.S. students to pursue science and engineering careers, and rebuild the competitive ecosystem through reform and tax, patent, immigrant and litigation policies.

The second report I would note just came out this last June titled *Research Universities and the Future of America*, a group that was chaired by Chad Holliday, former CEO of Dupont. It presented a bipartisan congressional group that requested it with 10 breakthrough actions vital to our Nation's prosperity and security. Now, one of the things that is somewhat unique about this report, and we are very proud of it, is that it proposes actions not just by the Federal Government but by state governments, business and universities themselves as well. The report recommends that the Federal Government should adopt stable and effective policies, practices and funding for university-performed research and graduate education. It also recommends reducing or eliminating regulations on university-sponsored research that increase cost and impede productivity. We are very grateful to Representative Mo Brooks, who has requested the GAO to determine ways in which this regulatory burden might be reduced.

Now, what actions are other countries taking? A couple of years ago, the then-Premier of China, Wen Jaibao, said flatly, "I believe firmly that science is the ultimate revolution." China's policies, investments and rapid progress derive from such beliefs of their political leaders. Just in January of this year, the European Union announced that it would fund two huge science projects, each at 1 billion euros, to "keep Europe competitive, to keep Europe as the home of scientific excellence." And looked at broadly, R&D investments by both industry and governments use to be totally dominated by the United States. Today, worldwide R&D investments are about a third in North America, about a third in Europe and about a third in Asia. This is a sea change. A final report at the request of the Department of Defense, the National Academies recently issued a report, "*The S&T Strategies of Six Countries: Implications for the United States*. It provides an overview and analysis of programs of China, Singapore, Russia, India, Japan and Brazil.

Finally, I would like to comment that in a lot of these discussions, and Ranking Member Johnson really headed me off at the pass because she clearly understands it very well, there is a lot of confusion of terminology of basic research, applied research and so forth, and I would like to use with the Chairman's permission, just a little bit of time to give you a perspective on this. Basic research is the search for knowledge by scientists of the natural world and how it works. Applied research, often conducted by engineers, suggests taking that knowledge, scientific knowledge, and conducting further investigations to forge into a useful application. Development moves the actual design to a mockup of a real product. So basic research gave us the electron and the structure of DNA, applied research gave us high-strength steel and the original Internet, development allows us to produce and market a new aircraft or a new computer system.

But things are changing. Today, much of what we do, I like to use the term "use-inspired basic research." This is work that is driven for—driven by the quest for an ultimate application goal but requires new fundamental, scientific and technological knowledge to get there. Use-inspired basic research gave us the transistor but it also gave us a lot of new discoveries about materials and quantum physics. Today, use-inspired basic research is giving us applications of new genomic understandings to medical treatment.

Now, 50 years ago, most R&D was conducted in big companies in the United States and it followed a sequential, linear process that you did a lot of basic research, got a lot of ideas. You sort of let the market figure out which one of these would be important. You then moved it to applied research, then you did development, finding the market of the product. Today, industry focuses primarily on development and it most certainly does not use this sequential linear process because technology moves too fast. It can't afford to do—industry can't afford to do much basic research where it is not clear that company will receive the payoff, and finally, the results of what we use to call applied research and development feeds so rapidly into the basic research itself that you just can't ignore it and follow the simple linear path.

Now, one of these two European projects I mentioned is to try to build the most sophisticated computer model in the world of how the brain works. Now, when you work on a problem like that, as we do in the United States, though will perhaps not at the scale the EU will—we will find out—you learn not only more things about the brain but you learn how to build better computers and it just circles around and all boats rise. But the one message I want to leave you with is that basic research is still done in universities primarily, including this new world of use-inspired basic research, with good interaction with companies and so forth produces the indispensable feedstock for companies and especially for young entrepreneurial companies that increasingly drive innovation, new products and jobs.

Mr. Chairman, Ranking Member Johnson, thank you so much for the opportunity to be here. I will be happy to answer any questions.

[The prepared statement of Dr. Vest follows:]

Testimony of

Charles M. Vest
President, National Academy of Engineering
The National Academies

before the

Committee on Science, Space, and Technology
U.S. House of Representatives
"American Competitiveness: The Role of Research and Development"

February 6, 2013

Chairman Smith, Ranking Member Johnson, Honorable Members:

I am Chuck Vest, President of the National Academy of Engineering and former president of MIT. Today I am representing the National Academy of Sciences, the National Academy of Engineering, and the Institute of Medicine.

It is a privilege to participate in this hearing.

We live in an age in which the ways we live, learn, work, travel, communicate, defend ourselves, and entertain are dominated by technology. New technology and evolving technology are the products of a process broadly known as research and development (R&D). Today, in 2013, the process of R&D is:

- Accelerating to higher and higher speeds of moving new scientific knowledge and new technology developments to marketed products and services,
- An increasingly complex process,
- A globalized process that is at once highly competitive but also cooperative, and
- A process that is driven by basic research and ultimately would die without basic research.

Let me cite six examples of 20th century innovations, all of which started with basic research conducted primarily or exclusively in American universities:

- Computers
- Lasers
- The Internet
- Deployment of the World Wide Web
- Basics of the GPS System
- Numerically Controlled Machines
- The Genomic Revolution
- Most of Modern Medicine.

There is not a job in America that does not depend directly on one or more of these.

There is every reason to believe that for American citizens to have a vibrant economy, security, and good health in the 21st century we will be even more dependent on rapid advances in fundamental scientific knowledge, development of new technologies based on these advances, and the ability of our innovation system to competitively deploy these advances into global markets as new or improved products and services. Furthermore, we face grand challenges in areas like sustainability, security, and health that are very large in scale and by definition global.

In this fast paced world, predictions about future technologies are difficult. When I graduated from engineering school, no one talked about going into Information Technology, because the IT industry didn't exist. Yet engineers of my generation invented it and it became our dominant source of employment. Today, things are moving even faster. As Thomas Friedman recently pointed out, when he wrote his book *The World is Flat* just a few years ago in 2004, Facebook, Twitter, iPhones, iPods, iPads, and cell phone apps didn't exist or were in their infancy.

So if we invest well in basic research and in education, we undoubtedly will be surprised by what new innovations arise. Despite my hesitation to make specific predictions, I would look for things such as amazing new materials for everything from smaller and dramatically faster computer and communication circuits to better roads and bridges and to lighter and safer automobiles and airplanes. So called Big Data and a new generation of artificial intelligence will likely enable us to better understand our world and organizations, dramatically improve medical diagnosis, and inform better policy and decision making. It is likely that a new generation of advanced robotics will affect everything from manufacturing to defense and highway safety, as we are seeing already in the growing importance of drones and an early generation of self-driving cars. There may well be unexpected practical advances in esoteric fields like quantum or biological computing, that might result in far more effective computer security and enable us to solve problems far more complex than we can now. Hopefully the current intense progress in studying the human brain and mind will lead to therapies for debilitating mental illness and also improve our learning and communication. It is likely that we will see serious breakthroughs in new energy technologies and new batteries or other storage devices. These are just a few personal thoughts and observations.

What are the barriers to continued success of our American innovation system?

Let me cite three major barriers that will be familiar to you, but that I believe to be of overriding importance:

- Our K-12 education system is failing far too many of our young people. We need to improve learning, especially in STEM fields for all American boys and girls so that they are prepared to enter the 21st century workforce and to be informed citizens. In my view, necessary improvements include preparing teachers with far better contemporary knowledge of the fields they teach, adoption across the country of voluntary education standards that promote exciting and sound learning through projects and experience rather than just boring memorization of facts, and sufficient investment in schools and teachers in underserved urban and rural areas.

- Immigrants, many of whom came to the U.S. as graduate students in engineering or science, have contributed hugely to our society and wellbeing, especially as faculty members and entrepreneurs. Yet in recent years, especially post 9-11, our federal policies have made it very difficult for the current generation of brilliant foreign graduate students to stay in the U.S. I would urge members of this important committee to promote policies that, as our Silicon Valley colleagues like to say, enable us to "staple a green card" to every PhD degree in engineering or science. In my view, we also need to allow larger numbers of tech-savvy entrepreneurs to come to our country to help keep our free-market innovation system rolling, even as we improve the education of our own young people.

- It is very familiar to you that for decades, the U.S. has had an R&D tax credit to promote corporate investment in research and development. However, this credit is debated and adopted year after year, leaving a troubling uncertainty that makes good corporate planning very difficult. So I also want to repeat a frequent plea that the R&D tax credit be made permanent.

As requested, I would like to delve further into policies that the National Academies of Sciences, Engineering, and the Institute of Medicine recommend the federal government pursue to ensure a leadership role in scientific discovery, technology development, and maintaining a highly trained and innovative workforce. Parenthetically, I very much appreciate the Committee's use of the term "leadership". Sometimes we talk so much about just being competitive that we lose sight of our traditional American goal of leading.

I must begin by referring to our baseline report from 2005, *Rising Above the Gathering Storm* and thank this Committee for supporting the authorization, passage and reauthorization of the America COMPETES Act that is largely based upon it.

I had the privilege of serving on the Gathering Storm committee – as did my colleague Shirley Ann Jackson - under the remarkable leadership of its chair, former Lockheed-Martin CEO Norm Augustine. The committee was composed of 20 leaders of American industry, academia, philanthropy, and former government officials. It included three Nobel Prize winners and two members, Robert Gates and Steven Chu, who subsequently became cabinet secretaries.

This committee was requested by a bipartisan group of members of the House and Senate to answer a specific question:

> What are the top 10 actions, in priority order, that federal policy makers could take to enhance the science and technology enterprise so that the United States can successfully compete, prosper, and be secure in the global community of the 21st century? What strategy, with several concrete steps, could be used to implement each of these actions?

It is the belief of the National Academies that the findings and recommendations of *Rising Above the Gathering Storm* are as relevant, and perhaps even more relevant today as when they were drafted. The reason is that after much discussion, the committee concluded that what needed to be tended to were the basics, and this need is unchanged. In summary, this report offered four broad recommendations, each backed by specific evidence and 20 explicit suggested actions:

1. Increase America's talent pool by vastly improving K-12 science and mathematics education.

2. Sustain and strengthen the nation's traditional commitment to long-term basic research.
3. Make the United States the most attractive setting in which to study and perform research so that we can develop, recruit, and retain the best and brightest students, scientists, and engineers from within the United States and throughout the world.
4. Ensure that the United States is the premier place in the world to innovate; invest in downstream activities; and create high-paying jobs based on innovation.

Among the specific suggested implementing actions were a federal scholarship program to annually recruit 10,000 science and math teachers who would major in a science, engineering, or math discipline and also be prepared for teacher certification; an annual increase of 10% in federal investment in long-term basic research each year for 7 years; establish an Advanced Research Projects Agency (ARPA-E) in the Energy Department to bring new entrepreneurial and academic players into energy innovation; provide 25,000 new competitive 4-year undergraduate scholarships in STEM fields to attract the best and brightest U.S. students; improve the visa and immigration processes for talented engineers and scientists; and enhance intellectual property protection for the 21st century global economy.

The America COMPETES Act has made significant strides in implementing some of our recommendations, but in our view, the responses to the education challenges at both the K-12 and university level have not been adequate to the scale of our problems.

There are two very recent National Academy Reports that I would like to commend to the Committee and its professional staff. Each deals with an aspect of American competitiveness in science and technology and/or analysis of actions in other countries.

Research Universities and the Future of America, released last June, was requested by a bipartisan group of representatives and senators and presents "ten breakthrough actions vital to our nation's prosperity and security". This study was chaired by former DuPont CEO Chad Holliday and included business leaders, academic leaders of both public and private universities, and former government officials including former Senate Majority Leader Bill Frist, and former chair of the White House Council of Economic Advisors Laura Tyson. This report makes specific recommendations for action by four parties: the federal government, state governments, business, and the universities themselves.

This report recommends that "within the broader framework of U.S. innovation and R&D strategies, the federal government should adopt stable and effective policies, practices, and funding for university-performed R&D and graduate education so that the nation will have a stream of new knowledge and educated people to power our future, helping us to meet national goals and ensure prosperity and security."

Because the invitation to this hearing explicitly asked about regulatory barriers, I note that one of this study's recommendations is "Reduce or eliminate regulations [on universities and sponsored research] that increase administrative costs, impede research productivity, and deflect creative energy without substantially improving the research environment." This recommendation is made with full acknowledgment of the importance of "accountability, transparency, and implementation of important policy and regulatory requirements". However, as one of many examples of the problem, the report notes that one public university reported that the costs of managing its Sponsored Project Research Pool grew from $3.5 million in 2005 to nearly $6 million in 2010. This is inefficient use of precious federal funds and there is a problem to be solved. A very major step in this direction could be made if the federal government and other research sponsors would strive to meet the full cost of research projects they procure from universities in a consistent and transparent manner.

We are very grateful that Representative Mo Brooks has requested the GAO to determine ways to reduce the regulatory burden on university research.

Although this report takes a broad view of public and private research universities, the overwhelming finding is the danger in the dramatic loss of state support for our public research universities. State appropriations to our public universities have dropped overall by 30% since the mid 1990s. The Universities of California, Michigan, and Washington have lost more than 50% of their state support in the last decade.

Although the federal government plays the absolutely essential role through research sponsorship, this report emphasizes the need for a problem-solving partnership of the federal government, state governments, business, and the universities. The National Academies are holding a series of working sessions around the country to gather ideas and build such partnerships. The first two workshops were held in Pittsburgh and Nashville. They attracted governors, U.S. senators, business leaders and others for very productive discussions and initiation of action plans.

What actions are other countries taking?

A couple of years ago, then-Chinese Premier Wen Jaibao stated flatly, "I firmly believe that science is the ultimate revolution." China's policies, investments, and rapid progress derive from such beliefs of their political leaders.

Last month, the European Union announced that it will fund two huge science projects at $1 billion Euros each in order to "keep Europe competitive, to keep Europe as the home of scientific excellence". The E.U. Human Brain Project aims to create the most accurate simulation ever of the functioning brain. The other project is in materials science and will focus on a material called ultrathin graphene that is both an excellent conductor of electricity and 300 times stronger than steel.

Looked at broadly, R&D investments by both industry and governments used to be dominated by the U.S. Today, worldwide R&D investments are about one-third in North America, one-third in Europe, and one-third in Asia. This is a sea change with large ramifications for U.S. science and industry.

At the request of the Department of Defense, the National Academies recently issued a report, *S&T Strategies of Six Countries: Implications for the United States*. It provides an overview and analysis of the science and technology strategies of China, Singapore, Russia, India, Japan, and Brazil, all countries that have dramatically increased their emphasis on science and technology for national objectives. Our study committee examined both investments and scientific and technological output of these countries and analyzed their progress toward their stated goals and objectives. In addition to documenting progress, this committee arrived at an unexpected conclusion: "cultural characteristics, rather than measurable indicators of economic and intellectual output, were the most valuable predictors of a country's success in meeting its S&T objectives." They concluded that of the countries examined, China and Singapore have made the greatest strides, having demonstrated an ability to adapt cultural characteristics to facilitate S&T advancement. It appears that successfully shaping a nation's ability to achieve its long-term S&T goals requires steps such as increasing the value given to education, eliminating corruption, gaining popular support for change, or dissolving social divisions that negatively impact a country's workforce.

This report recommends that the "U.S. should assess the national security implications of the continuing revolution of global S&T as a matter of urgency. That assessment should include an examination of its own ability to integrate successfully into the global innovation environment, to ensure that it remains in a position that allows for continued prosperity and national security."

I have found in many discussions about R&D and innovation that certain terms, including "basic research" and "applied research" cause confusion. Let me give you my perspective.

Basic research in science is the search for knowledge of the natural world and how it works. *Applied research,* often conducted by engineers, suggests taking the scientific knowledge discovered by scientists and conducting further investigations to forge it into a useful application. *Development* moves to the actual design and mock up of a product.

So basic research discovered the electron and the structure of DNA. Applied research gave us high-strength steel and the original Internet. Development prepares us to produce and market a new aircraft or a computer system.

But there is another very important type of research called *use-inspired basic research.* This is work driven by the quest for an ultimate application goal that requires discovering additional fundamental new scientific knowledge to get there. Use-inspired basic research gave us the transistor – together with a lot of new discoveries about materials and quantum physics. It also is giving us applications of genomics to medical treatment.

Fifty years ago, most R&D was conducted in large companies that followed a sequential *linear process* starting with basic research, moving to applied research, then doing product development, and finally marketing that product.

Today, this situation is more complicated. Almost no companies do all of this work in house, and they do not follow the sequential process. Companies do very little basic research because they can't afford it especially when it is not clear that the company itself will be the primary beneficiary of the results. Companies do not follow the sequential, linear process because technology moves too fast, and because the results of applied research and development rapidly feed back into the basic research.

In the United States, industry focuses mainly on development work. Universities now do most of the basic research and use-inspired basic research, and the federal government is the dominant supporter of this work. Thus university research produces the indispensible feedstock for companies, and especially for young entrepreneurial companies that increasingly drive innovation, new products, and jobs.

Mr. Chairman and Ranking Member Johnson, this concludes my testimony. I hope I have responded to your questions in a way that is useful. Much of our economic future depends on us being smart and agile stewards of the U.S. R&D base, and we in the science and engineering community are ready to help you accomplish that. I'll be happy to answer any questions you may have.

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Chairman SMITH. Thank you, Dr. Vest, and thank you all for your testimonies today, and I will recognize myself for five minutes to ask questions.

And Mr. Templeton, I would like to address my first question to you, and let me preface it by saying this, that in the United States every year, $400 billion is spent on research and development. About $140 billion comes from the Federal Government. Those are huge amounts of money but they also have the potential to do a huge amount of good. So my question is, where would you target the government's research and development funds to get the best returns, and what might those returns be?

Mr. TEMPLETON. Well, Chairman Smith, I guess the way I would describe it is, if you take a look at the innovations that Dr. Vest just described, investment in physical sciences has really been diminishing over the past 30 years as a percent of GDP. A lot of the studies, like in 2007 with *Rising Above the Gathering Storm* talked about doubling that over the next seven years. So I think that direction is the correct direction, and then to the question which is an important one, how do you shape that or how do you make decisions of where to apply it, I think we have got some good examples that have worked well in both federal agencies as well with universities, and with public companies to have peer-review processes to understand where are the most promising ideas, and if we had—someone had noted, if we had an exact view of what the future was, we would be magical. We are not going to get that but what we want to do is use our best minds to try to shape that in the peer-review process. I think that is going to be the best line.

Chairman SMITH. Thank you, Mr. Templeton.

Dr. Jackson, you mentioned in your testimony a few minutes ago, STEM education—science, technology, engineering and math—the Federal Government spends more than $3 billion a year to improve STEM education in our country but we have yet to see significant results from this investment. Do you have any suggestions as to what we should do to improve that record?

Dr. JACKSON. I do have a few. Thank you. First, I would say that there are three areas we need to focus on. One is improvement in K–12 education, the second is stemming losses in the undergraduate pipeline in STEM education, and the third, creating appropriate bridges to the next level.

With respect to K–12 education, believe it or not, I fundamentally am one that says let us get back to basics. I am a theoretical physicist by background, and one cannot do that without a very strong, sophisticated math background, but to do that, one has to be able to do calculus and partial differential equations and all of that, but one can't do that without understanding geometry, trigonometry, algebra, etc. One cannot do those things if one cannot add, subtract, multiply, divide, understand a little bit about logarithms, fractions, percentages, etc. So the point is, it is cumulative, so we have to think about that, as we think about how K–12 education is structured. Secondly, we need it to be outcomes focused, not just in terms of testing but in terms of the ability to use concepts, to use what is learned. Third, we have to strengthen the teacher corps, and I am one who happens to believe that at least for upper-level secondary science and math subjects, that having discipline-based teachers is useful. And finally, we need to be able to use technology itself in a smart way. We are educating digital natives. I am a digital immigrant, latecomer, but we need to be able to use technology to create the right kind of immersive experiences, to educate those in science and technology.

The point about the undergraduate pipeline is that there is a much larger dropout rate than people might realize in the first two years of undergraduate education, generally, but including in STEM subjects where students opt—out of those subjects. So there are beginning to be discussions about looking at how science is taught in the first two years of the universities and colleges. And third, when I speak of bridges to the next level, there really needs to be work that puts the basics and applications together. That is how we can draw in young people and they are learning things without even knowing they are learning. Thank you.

Chairman SMITH. Thank you, Dr. Jackson.

Dr. Vest, in your testimony you said if we invest well in basic research and in education, we undoubtedly will be surprised by what new innovations arise. What are some of those new innovations?

Dr. VEST. Well, "surprise" is the keyword, but since this is one of the questions that was forwarded to us prior to the hearing, I tried to give it a little bit of thought, and as Mr. Templeton was reminding us earlier today, it has been often said that the best way to find out what the future is, is to invent it, and I guess that is what we are all about. But I would point out a few areas that I think are likely. One is new materials. Investment in material science and engineering works on everything from smaller, faster computer circuits to better highways to better bridges. Mr. Templeton's company is actually driven by a philosophy on what is happening in materials available for semiconductors, for example. The second area is the combination of so-called big data and the new generation of artificial intelligence that if we use it well is going to help us understand the world better, make better decisions and probably give us dramatic improvements in areas like medical diagnosis and working together with humans, by the way, computers plus humans doing better medical diagnoses and better policy and decision making. Then it is likely that this rapidly advancing new generation of advanced robotics is going to affect everything. For manufacturing, not just on the big fancy, high-tech company side but on the small manufacturing side as well and also obviously has implications to areas like defense and highway safety. We are already seeing controversial—though it may be this growing—importance of drones, which is a form of robotics, and a new generation of self-driving cars. There is lots of reasons to sort of intuitively be worried about that but there is lots of data that is showing that it could build us ultimately in a couple of decades a much safer highway system.

And finally, these really unexpected things, there are these very esoteric fields like quantum computing and biological computing that just may pop up as reality one of these days, giving us much better computer security, which we all know is a big issue, and allowing us to solve more complex problems than we currently can. But surprise is the big thing, and I want to just underscore what my good friend Dr. Jackson said: all this work today by the young people crosses all the traditional disciplines and it is really these unusual or used to be unusual combinations of scientific and technological input that will give us the real surprise innovations. Thank you.

Chairman SMITH. Thank you, Dr. Vest.

The gentlewoman from Texas, the Ranking Member, Ms. Johnson, is recognized for her questions.

Ms. JOHNSON. Thank you very much. And let me express my appreciation for all of the witnesses.

My question is pretty basic. I was around during the *Rising Storm*. We are in the midst of a storm, and I am not sure how much change we have made, though we try. But the most recent research that I have read about students getting into college and then changing from the STEM interest concerns me greatly. It concerns me because the students who seem to leave those fields more frequently are the women and minorities, the growing population. What storm do we need to get gathering here to see if we can change the course of this? Because I really sincerely feel this is the future of our Nation and competitiveness. Anybody who wants to try?

Dr. JACKSON. Well, since I do educate a few of them, as I said, I think we are finding that the first two years seem to be very seminal in terms of how students are educated, how they are nurtured. At Rensselaer, we actually have a multigenerational approach for women in engineering. We have faculty who mentor postdocs who mentor graduate students who mentor undergraduates, and what we find is that once the women—and this is women across all ethnic groups, by the way—opt truly into science or engineering. They actually graduate at higher rates than the men. So I think there are subtleties to how this all works.

There remains a problem with respect to underrepresented minority males, but it is actually embedded in an issue that has to do with the fact that young men overall are not graduating at the same rates as women. So we are undertaking a special task force at the university to look at this question about how do we create more stickiness for students in the first two years, and looking at our teaching methodologies while at the same time undertaking a particular study about male students and what is happening with them; and we do think there are lots of issues having to do with cognition and learning, how we structure courses. And in fact, I am a member of PCAST and we in fact issued a report discussing some of these things.

Dr. VEST. I would only like to add to that that we need to move our perspective back, not to make an excuse, but we need to move it back to the K–12 system and build a good continuum from K–12 through the kinds of things that RPI and MIT and so many other schools are now trying to do, and I would add to the very, in my view, correct list that Dr. Jackson gave earlier. I want to emphasize one of her points and add one thing to it. I really believe that exposing kids from inner city to countryside to suburbs to science and math teachers who have actually graduated in the field they teach. We can do this. This is the primary A number one recommendation of the Gathering Storm report and very little happened to it. So the idea is very simple. We need to deploy a set of scholarships to attract young men and women to go to college, to major in computer science or electrical engineering or physics or chemistry and at the same time be certifiable as K–12 teachers.

Secondly, and I hope I am not getting a little too much to the political side, I am a big believer that we need to adopt voluntary standards, voluntary standards across our states in STEM fields just as we have in mathematics and in English, and these standards need to emphasize learning science by doing it, project based, bringing the excitement, the sense of discovery. This is what is going to attract more kids. Just look at things like the Maker movement. It attracts kids from all over the socioeconomic spectrum. Look at Dean Kamen's first project that is in every inner city in the country as well as the wealthy suburbs. This is the way kids today get excited. They get excited by doing. And I think if we could sort of focus on those two things, we could get more people in a more dedicated way into the pipeline, and then if we can top that off by improving the way we teach in universities somewhat along similar directions, maybe we can get there, but this—to me, this division between where kids come from and what their chances are to succeed, it is not America. We really have to get at this.

Chairman SMITH. Thank you, Ms. Johnson. The gentleman——

Ms. JOHNSON. Well, I think Mr. Templeton——

Chairman SMITH. Mr. Templeton?

Mr. TEMPLETON. I was going to say amen.

Ms. JOHNSON. Thank you very much.

Chairman SMITH. Thank you, Ms. Johnson.

The gentleman from California, Mr. Rohrabacher, is recognized for his questions.

Mr. ROHRABACHER. Thank you very much, Mr. Chairman.

Let me ask Mr. Templeton, does your company benefit directly from federal research projects? Do you actually get direct money from the Federal Government to do research for your company?

Mr. TEMPLETON. And that was one of my comments. To be very clear, this is about funding going into university systems for basic research, not our company, so a very simple answer.

Mr. ROHRABACHER. Okay. So there is a certain amount of money that your company is supporting going to a direct research project for a university which then your company, as other companies, then benefit from that research?

Mr. TEMPLETON. No, we have a choice and we do choose to participate alongside the Federal Government in long-term basic research as well. Very much some of the same vehicles could be the Nanoelectronics Research Initiative, NRI, or focus centers, so this will be TI putting funding into universities for long-term basic research, and we will do a small percentage of that, so we are at the table and helping to shape an opinion of where that——

Mr. ROHRABACHER. How much money does your company actually invest in this type of long-term future investment?

Mr. TEMPLETON. It would be tens of millions on an annual basis, so it is not a trivial amount.

Mr. ROHRABACHER. Okay, tens of millions. Now, let me ask you this. Your company manufactures chips?

Mr. TEMPLETON. Yes, sir.

Mr. ROHRABACHER. Okay. What percentage of your production is in the United States, and do you manufacture in China?

Mr. TEMPLETON. The majority of our production today is in the United States. We opened our most recent wafer fab, and in our industry, 300-millimeter wafers or 12-inch-diameter wafers are leading edge. We opened that facility in Richardson, Texas, back in 2007, broke ground, put it online in 2010. I would estimate that probably 40 percent of our chips are manufactured in the United States but we also, to your direct question, manufacture some chips in Europe. We have a facility in China. We have facilities in Japan as well, so we are a global manufacturer.

Mr. ROHRABACHER. What percentage of your chips are manufactured in China?

Mr. TEMPLETON. It would be a very small percentage right now.

Mr. ROHRABACHER. Ten percent?

Mr. TEMPLETON. Oh less, significantly less.

Mr. ROHRABACHER. But your industry, there are major components of your industry that are engaged in manufacturing these types of things in China.

Mr. TEMPLETON. There are other parts of the industry that do manufacture in China, yes.

Mr. ROHRABACHER. Well, we appreciate the fact that your company is doing a lot of manufacturing here, and we appreciate that investment.

It says here we have $400 billion in this type of research that is going on. Does that figure, $400 billion annually, does that calculate in what individual inventors put in to the mix or are they just not part of the calculation?

Mr. TEMPLETON. I don't know if they are. They are probably not going to be a significant percentage, okay, as measured by dollars but about 60 percent of that would come from private or companies and 40 percent of that, as Chairman Smith commented, would be federal funding.

Mr. ROHRABACHER. When we are talking about private inventors and their impact on new discoveries, how would you place them in terms of government programs coming up with something new, corporations coming up with something new versus the individual inventor community coming up with something new?

Mr. TEMPLETON. I think if you look at and take Dr. Vest's list of the types of breakthroughs over the past 50 years, the invention of the transistor or ARPANET, which led to the Internet, these tended to be very significant basic research programs that weren't in the minds of any one individual, even at a university but typically a network of universities and a network of people.

Mr. ROHRABACHER. So the foundation, but we do know that some very significant fortunes have been made utilizing that information and creating something that really was put to use in the marketplace, and my time is running here, but just in terms of the inventors, yesterday we heard about the investment again and government provided the money for the direct research that ended up with somebody in the very end of the process was the MRI. Well, I happen to know the guy who has the patent for the MRI, and, you know, without him, there wouldn't have been an MRI as well. Do you think that there has been—do you think our patent protection for these innovators, the inventors, is going in the right direction or the wrong direction?

Mr. TEMPLETON. I think in general it has moved in a positive direction over the past five years, trying to find that very careful balance of what is good to protect invention but not, you know, move off into where patent trolls and many debates go around that topic. Depending on who you are, you have a strong opinion one way or the other.

Mr. ROHRABACHER. The Chairman and I have differences of opinion on this. Thank you very much for sharing your views with us today, and thank you, Mr. Chairman.

Chairman SMITH. Thank you, Mr. Rohrabacher.

The gentlewoman from Oregon, Ms. Bonamici, is recognized for her questions.

Ms. BONAMICI. Thank you very much, Mr. Chairman, and thank you so much for scheduling this hearing. Thank you to all the witnesses, panelists. I really appreciated the article in the Politico, Mr. Templeton and Dr. Jackson.

The testimony that you all presented to the Committee contains many common elements, and indeed, they are topics that are frequently discussed in this room, especially the importance of promoting STEM education and the role of creativity and innovation in maintaining America's leadership position in the global economy.

Now, when I am out talking with constituents and industry leaders about this topic in my district in Oregon, especially about the role that creativity and innovation play in driving our economy forward, many of them express the importance of STEAM education, which is integrating arts and design in traditional STEM fields. Innovative companies across my district from companies like Nike and tech giants like Intel rely on employees with a mind for science but an eye for design, and we have discussed how integrating arts and design education into traditional science education can yield the sort of creative, innovative workforce that many of you identify as essential. And beyond just the benefit for the industry, bringing arts and design into STEM classrooms can help keep students engaged, and I know, Dr. Jackson, you talked about drawing students in. I want to tell you, I visited a STEAM elementary school in my district that took STEM and added arts and design. Those kids were engaged. They were acting things out. They were studying soil erosion and graphing things and drawing charts and planting a garden and playing with worms. I mean, they were really, really engaged in everything that they were doing.

So in order to keep students engaged, I want to have a discussion about STEAM. And Mr. Templeton, you affirmed that government primarily conducts basic research while industry focuses on the D side of R&D, developing products for commercial application. In your experience at Texas Instruments, can you discuss the importance of creativity and design to this product development process?

Dr. Vest, you discussed improving learning in the STEM fields for students and suggested promoting exciting learning through projects and experiences rather than just boring memorization of facts, and as you see it, could arts and design play a role in STEM education, especially in the learning atmosphere you envision with your comments? Thank you.

Mr. TEMPLETON. Well, on the aspect of creativity, the simple answer on that is yes. It is one thing to have numbers and concepts. If they cannot be brought together and visualized and turned into a product, it is knowledge that will not lead to productive things. It is also the case then if you look at STEAM efforts, we have very recently done something with one of the school districts in North Texas, and I think it has got great potential for the creativity that brings along. I do think it is important while we look at that, back to Dr. Jackson's comments, we have to be mindful of the basics, be it the math and science principles, because if we don't have that foundation in place, you can never get to some of the higher-level concepts as well, so I think keeping those in balance is a wonderful thing.

Ms. BONAMICI. Thank you.

Dr. Vest?

Dr. VEST. It is a very perceptive question, in my view, and one I get pretty excited about, so you may have to shut me off, Mr. Chairman. But I cannot imagine MIT without its visual and performing arts component. It would not be MIT. We would not attract the same kind of kids. And it is very much a part, in my opinion, of what has to happen at both K–12 and in undergraduate and even graduate education in our universities. *Rising Above the Gathering Storm* tried to emphasize, we are not telling all kids we want them to become professional scientists and engineers but everybody needs to know some fundamentals today about science and engineering. My experience, if you look at virtually any of the real good high schools that are succeeding, High Tech High in San Diego and so forth, the integration of arts into their curriculum is a very important part. I commented on the Maker movement. This attracts kids from left brain, right brain, everything in between, and I am frankly a big believer in the STEAM movement. There is a hearing somewhere in Congress coming up over the next several weeks that my wonderful friend John Maeda from RISD, the Rhode Island School of Design, is helping to organize. So I am a big believer in this, but it always leaves me in an odd position because I also know that we are failing in our core STEM areas, so it is difficult to talk about the breadth, but yes, arts and the humanities are a very important part of building creativity.

Ms. BONAMICI. Thank you. And I am afraid I am out of time, but Dr. Jackson, if you wanted to——

Dr. JACKSON. You didn't pose the question to me, but we believe so much in it that we have built an experimental media and performing arts center at Rensselaer, and it is both a very high-end cultural and performing arts platform and it is a research platform at the same time. It brings the arts, engineering, the sciences, computer sciences all together, and we have various venues within it, but one in particular allows us to do visualization, animation, simulation, acoustics, haptics, haptics where you can simulate touch. All of this requires bringing all of the disciplines together, including in the arts. We have a games and simulation arts and sciences curriculum, and it uses that whole structure to animate what students do, but at the same time, we feel that fundamental studies in certain fields of the humanities, arts and social sciences are critically important and so we have built those up as well.

But you know, it is funny, we have gotten into these buckets about what constitutes the liberal arts versus what constitutes science and engineering, but if you go all the way back to Cardinal Newman about the original definition of the liberal arts, they were in fact together.

Ms. BONAMICI. Thank you very much. And I am out of time, and that meeting is a week from tomorrow, and we will let the Committee Members know if they would like to attend.

Chairman SMITH. Thank you, Ms. Bonamici.

The Chairman Emeritus, the gentleman from Texas, Mr. Hall, is recognized.

Mr. HALL. Mr. Chairman, thank you very much, and this is a very unusual and talented group that are giving us your time, the time it took you to get here, the time it took you to appear before us, give us your testimony, get back to your place of occupation. I know Rich Templeton very well and admire him. Eddie Bernice and I, I am sure Eddie helped to ask you to come here, Rich. We are proud of TI. Erik Jonsson, Gene McDermott, Cecil Green, all those people created the University of Texas at Dallas and were very generous in giving around 1,100 acres to that university. I was the Senate sponsor of that with a guy from the House and I am very proud of the university that you all have created. And Mr. Rohrabacher asked about your support. I could talk all day about the support of that university.

I will ask you this one question about STEM graduates. And I know that your dream of Dallas Engineering School finally became a reality in 1986 and the students that you have and you have been a part of TI's history. What about the STEM graduates? Are there enough available in the United States to meet your current and future needs?

Mr. TEMPLETON. Well, Mr. Hall, first, thank you for the very complimentary statements about many of our founders, who also had deep histories at both MIT and at RPI. If you look in many ways, the percentage or the amount of people that we hire on an annual basis, we are fortunate because of our reputation that there is enough available. The danger is, that does not apply, I believe, to all industries as you go down through that and I think that supply will be under continued pressure if we don't get K–12 STEM education turned and moving in the correct direction.

Mr. HALL. What are some of the key factors in motivating students to pursue STEM degrees?

Mr. TEMPLETON. Well, I think it has been touched on by both——

Mr. HALL. Well, I had to leave, and I have to leave soon to go back to another Committee to vote. I am sorry to touch on it a second time if it has already been asked.

Mr. TEMPLETON. Oh, no, I will make it very simple. I think it has been talked about. Make the business come alive. If you look at many high school students, especially if you look at women trying to consider a career in science and technology, if you get to the undergraduate level that Dr. Jackson had talked about, and you see nothing but four years of math and science classes ahead of you before you can apply it to something that makes it come to life, you lose a lot of people during that time. When we look at the world of bioengineering to where you really can't see the impact you can make in lives and it really brings the potential career and the impact that you can have alive in young people's minds, then I think that is the secret to grow or to turn that trend around.

Mr. HALL. The best practices that the Federal Government could implement to strength our Nation's R&D and maximize the use of taxpayers' dollars, are you a witness to that?

Mr. TEMPLETON. Well, I pay attention more to results, and right now if I look at the results coming out of K–12 STEM education in the United States, we continue to be ranked very low on most national or most global ranks, so I think the work that we have as a Nation is still in front of us on that.

Mr. HALL. All right. I thank you, and I thank you, Mr. Chairman.

Chairman SMITH. Thank you, Mr. Hall.

The gentleman from Massachusetts, Mr. Kennedy, is recognized.

Mr. KENNEDY. Mr. Chairman, thank you, Madam Ranking Member, thank you very much for calling this important hearing. To the witnesses, thank you all very much for your testimony. As a resident of Massachusetts, we are acutely aware of the importance of R&D and greatly appreciate your time in coming here today.

Mr. Templeton, I actually have a quick question for you that is slightly off topic but of important interest back in my district in Massachusetts and so, Mr. Chairman, I hope you will forgive a quick diversion. As I am sure you are aware, Mr. Templeton, Texas Instruments operated a manufacturing facility in Attleboro, Massachusetts, for several decades. Until it was sold in 2006, the company was a major employer in the area and an active member of the local community. It remains well respected in the city and in the surrounding areas still today. That being said, in the years since the Attleboro plant was closed, the cancer rate amongst former employees has been alarming. Specifically affected are those men and women who were employed by the company between 1953 and 1968 when TI was involved in the federal nuclear program. As part of the Energy Employees' Occupational Illness Compensation Program through the Department of Labor, money has thankfully been made available to those workers who are now suffering from crippling illness. I know that TI has designated an internal point person for the former workers who are seeking information from EEOIC, and I commend you and TI for doing so.

But what I am hearing from many residents back in the district is that very few of the thousands of former employees in the Attleboro area are even aware that this program exists and that there are benefits available to them at all. They have seen minimal outreach efforts to ensure that those in need know how to get the help they so deserve. I read this week about Steve Foster from Taunton in the local newspaper. He is suffering from thyroid cancer. His brother also has cancer. His wife and father both died of cancer. All four worked in the Attleboro plant. Yesterday I spoke to Larry Darcy, a resident of Rehoboth, Massachusetts, who was diagnosed with kidney cancer in 1992. Larry went out of his way to credit your company for the opportunities that it gave him and his coworkers. Over 180 of those coworkers from the Attleboro plant that he is aware of have contracted some type of cancer.

I tell this story, sir, not to cast blame. The human cost of this country's nuclear development in the 1950s and 1960s is not unique to Texas Instruments or to Attleboro, but I do believe that TI along with the Federal Government has a responsibility to the men and women that we put in harm's way. While we can't take back the exposure to the radioactive or toxic material that so many suffered, what we can do is absolutely everything in our power to make sure that we ease their pain today. So, sir, I would like your opinion on how my office can work with your company and the Department of Labor and Department of Energy to ensure that we are doing all that we can to get the compensation for those who need it. To start, I am wondering if, one, there is any light you can shed on the process that TI goes through to redoubt the former employees in this situation or similar situations, and two, what my office or the Federal Government can do to assist you in this process? The money is there, the program is there and the need, tragically, is also there. The communication is not, and we need to try to fix that.

Mr. TEMPLETON. I think, Mr. Kennedy, first, as you know, we have been in very close contact with the DOL, or Department of Labor, as well as the Department of Energy, and I think you described the actions we need to take which is, we need to stay in contact both between the appropriate government agencies and your office. We have been very active with the Departments to make sure any information we could help with was available. We need to continue that and take a look. If there is more than can be done, we should be doing it with you.

Mr. KENNEDY. Thank you, Mr. President. Which—is there—I would appreciate further communication with you and the designated point person from your office to try to understand if there are employee lists that go back to that time. I understand you have a very generous pension plan, that there are still health care benefits that are being paid to your employees, which your employees went out of the way to credit Texas Instruments for, but if we can somehow facilitate that transfer of information to the government so that they can reach out to those individuals, many of whom don't even know that there is benefits there to cover medical bills that are now soaring into the thousands of dollars?

Mr. TEMPLETON. We can certainly get the right contacts to you so that can be done.

Mr. KENNEDY. Thank you, sir. I yield the balance of my time, Mr. Chairman. Thank you.

Chairman SMITH. Thank you, Mr. Kennedy.

The gentleman from Georgia, Mr. Broun, is recognized.

Mr. BROUN. Our government is broke. Many Members of Congress are either oblivious or in denial of that fact. We are spending more money than we are bringing in. We are headed towards a total economic meltdown of America if we don't make some changes. Now, both parties have been guilty of uncontrolled spending here in Washington. Promoting science as well as research and development is extremely important for America to get back on a sustainable fiscal course. We must start making responsible decisions and choices here in Congress.

With that said, Mr. Templeton, it is well known that the United States has the highest corporate tax rates in the world. It is 35 percent at the federal level. When you add state and local taxes, it is much higher than that for employers and job creators here in America. Please discuss how the rate impacts businesses and how it affects those investment decisions, including how it can be factored into decisions regarding where to locate manufacturing facilities or how much to invest in R&D. How would business investment, hiring and overall U.S. competitiveness be impacted if we eliminated corporate taxes altogether such as my JOBS Act does? The JOBS Act will permanently reduce corporate taxes to zero and capital gains taxes to zero, and I think personally it would be a huge economic boon, and instead of raising taxes would raise taxpayers with good-paying jobs. Could you please discuss that, Mr. Templeton?

Mr. TEMPLETON. I will not disagree with your final conclusion. I also know it brings the double taxation dialog that many debate, especially in difficult budget times. But I think the conclusion that you are leading to in the question is very clear. We compete against companies that could be headquartered in Taiwan, for example, and some of them because of government policy virtually have a zero tax rate, and so if we try to operate in the United States market or work against some number incrementally at the 35 percent level and you have got shareholders that have an expectation for a company in Taiwan that operate at zero, it puts a very difficult situation in place for the long term, and even further to the point, and you have seen some of it where companies are faced with, should they move their corporate headquarters to different countries if they are trying to be responsible to their shareholders. I think that is a really dangerous slope to end up on as a country. So I think that the conclusion of your points is very accurate on that.

I think it also does come back to by investing in university research, by having those ideas being developed here, we do give advantages to being U.S. headquartered and what we need to do is not be uncompetitive against some of these other countries and then I think we can get great gains from where we are today.

Mr. BROUN. Mr. Templeton, I believe that the high tax rate and the regulatory burden that the Federal Government has put on business and industry is what is driving manufacturing jobs offshore, and I believe very firmly that we have to bring those jobs back to America because that is what is going to get our economy going again, create those good-paying jobs, particularly in areas of science, technology and engineering, medical science. I am a physician. Do you have any suggestions about how we can look at the regulatory burden and tax burden, besides passing my JOBS bill, which I think is critical to bring those manufacturing jobs back to America? Can you give us some suggestions about what we can do to look at the regulatory burden as well as the tax burden and give us help in getting these shackles off of business and industry, our job creators, so that we can start having a strong manufacturing industry here in this country? And thank you for—I want to thank you for Texas Instruments having the manufacturing that you all do here in this country.

Mr. TEMPLETON. Mr. Broun, you know, the simplest way that I think about this is, we have five percent of the world's population, which says 95 percent of it is somewhere else. So when we think about economic growth for our country and for companies that are headquartered in the United States, we have to have policies and plans that let U.S.-headquartered companies compete globally because it ends up creating great opportunities and great economic growth in the United States. I think therein lies the beginning of that policy on how can our U.S.-headquartered companies be highly competitive. That then brings in issues of tax. That brings in issues like today's hearing on research and investment into basic universities. It brings into scope, you know, issues on regulation. We want to be able to operate well but we need to also be able to operate competitively on a global basis, and when that frame is in place, I think you can get to those points or those conclusions pretty quickly.

Mr. BROUN. Thank you, Mr. Templeton. I yield back.

Chairman SMITH. Thank you, Mr. Broun.

The gentleman from California, Mr. Bera, is recognized.

Mr. BERA. Mr. Chairman, thank you for convening this hearing. I will make a quick comment. As a former Associate Dean at the University of California Medical School, we did look extensively at the loss of undergraduate talent, and that clearly is tied to our K–12 system, particularly in lower-income communities and students just not being prepared. If we can hold on to those students when they get to their junior year, they do make up the gap, but we lose far too many of our students there.

My question, I will direct it at Dr. Jackson. You are also coming out of a research university background. A key element that we need to focus on is that technology transfer issue, how academia and industry partner, and if you could give us some specific recommendations, and I would open it up to any of the panelists, how we can do that better, how we can work on that partnership?

Dr. JACKSON. Thank you. I would say a couple of things. First, there are many mechanisms. This whole question about technology transfer, how ideas go from the university into the marketplace is a complex one and it happens within multiple groups. They are public. They are university-industry partnerships, industrial liaison programs. There are entrepreneurs who take the intellectual property they develop in the university, out of the university. The university licenses out intellectual property. All of these things are pathways for that. I think there is a balance that one has to strike, as a university president, in terms of the focus on the basic research and the fundamental learning that goes along with that, and the exploitation of the intellectual property to move it into the marketplace and fundamentally we are focused on both. We actually have a 1,250-acre technology park that is actually home to about 70 enterprises, primary technology based. We have what is called the Emerging Ventures Ecosystem, which specifically seeks into the research, work with our faculty, find where there is exploitable, important intellectual property, and then look for the right translational pathway, whether that pathway has to do with licensing, with helping the faculty member launch a company, joint venturing, etc. We also operate, as part of, that an incubation program, but in our case, we went from having one fixed incubator to having kind of a virtual incubator where we broker the right space for companies. This is very important.

And I spoke in my oral remarks about shared infrastructure. A big problem for many startup companies, particularly in areas of new technology, has to do with the so-called valley of death where they go from the sort of very initial startup phase and they may get angel investors for that, to be able to scale what they do, to do prototyping and then ultimately get larger investment. And so there has to be a way for that to happen. It is interesting that we, in some ways, do that through certain mechanisms like OPIC and the Ex-Im Bank when it comes to companies doing things out of the country. But we need something that relates to that kind of thing inside the country. So these are some of the things I would say.

The other has to do with patent policies, and on the one hand, the new patent legislation is very helpful. It is very helpful to companies in particular. But it has caused universities to rethink, particularly the piece having to do with "First to File." On the other hand, in terms of the kind of domain within which to operate and how to ensure that, it has been helpful. So all of these kinds of mechanisms exist. I also believe that—and Chuck talked about making the R&D tax credit permanent. That has an effect that spurs, I think, companies to do more, but it also, in an interesting way because of that spur can increase the interest of companies in working with universities in more basic areas.

Mr. BERA. Great. Thank you.

Chairman SMITH. Thank you, Mr. Bera.

Dr. VEST. Mr. Chairman, may I add to that?

Chairman SMITH. Yes, Dr. Vest.

Dr. VEST. Just very quickly, I learned four things about this in 14 years as President of MIT and two of them have been greatly supplemented by what I have learned at the National Academies. First of all, we need a simplified policy patent, and I am not talking about federal policy now; I am talking about agreements between universities and companies, at least for modest-scale projects. It should be a boilerplate, no negotiation kind of package, and we are making some progress toward that.

Second, what we most need with big companies, long-term strategic partnerships, sticking with it in ways that honestly the Federal Government frequently can't do. There is a great example of Mr. Templeton's company and a few faculty at MIT in the area of signal processing. It has been running for decades, not at a terribly high financial level but it has been really productive.

Third, and not every university can do this, I would admit, but we need some large-scale partnerships by which I mean significant multimillion-dollar partnerships between the university and a company because only then do you get real interaction with the thought-leaders in the company. You can't do many of them but a few of them are important.

And finally, on the entrepreneurial side, which is so much of what is "technology transfer" today at an RPI or an MIT or virtually any of our great public or private universities, creating opportunities for young people to get coached. Hands-on coaching by real entrepreneurs and real VCs is just worth its weight in platinum. It is the real key to building up that ecostructure. Thank you.

Chairman SMITH. Thank you, Dr. Vest. Thank you, Dr. Bera.

The gentleman from Mississippi, Mr. Palazzo, is recognized for questions.

Mr. PALAZZO. Thank you, Mr. Chairman, and I thank our witnesses for being here today. There has been some very good discussion.

You know, there is no doubt that foreign competitors present a substantial challenge to U.S. economic competitiveness and some of those reasons why they are doing well is some of the self-inflicted wounds that we have caused to ourselves such as having an antiquated tax code that really is punishing our corporate job creators in America as well as the job-killing regulatory regime that is pushing a lot of American jobs overseas and actually pushing a lot of businesses just out of business, killing small business as well.

One field of endeavor for American competition is still space. So my question is going to be space-specific. I am pretty much a one-trick pony when it comes to this Committee, and anything space and aeronautics is what I like to talk about.

America used to be in a space race with the Soviet Union, and today, unfortunately, NASA purchases seats on the Russian Soyuz rockets at $16 million per astronaut to launch to the International Space Station that we built with the now-retired space shuttle. So my question is for everyone. How do you think America's ceding leadership in space like that translates to the sense among many Americans that we are no longer a technology leader? And we will start with Mr. Templeton.

Mr. TEMPLETON. You know, I think in many ways, as many on this Committee probably know, the space race was a very polarizing, very inspiring challenge back in the 1960s and provided tremendous investments that led to things like the semiconductor industry. I suspect when the space race was underway there was no one sitting around in federal labs or at an agency planning out semiconductor industry leadership 30 years from when they began that race. So, you know, I am not qualified to comment about the specifics of space or not, but I think wonderfully challenging goals, okay, really help this country, really bring energy and inspiration to invest and go try to do great things, and whether that is a space objective or things in the biomedical field that were talked about, I think those have, you know, great potential when we think about this challenge in front of us.

Mr. PALAZZO. Dr. Jackson?

Dr. JACKSON. Thank you. You know, it turns out that one of my predecessors as President of RPI, Rensselaer, was George Lowe, who basically was the operations director who ran the Apollo program that put man on the moon. As well, a number of our graduates have been involved in more recent work in designing and launching the Mars Rover. So it is a big part of our history and tradition. But what I would say is the following. There are a number of pieces, some having to do with basic research, and I will mention just a couple of things with that, some having to do with infrastructural questions, and then the third having to do with the overall industrial capability to do these things.

On the basic research, if you think about space missions, they depend on fundamental science and people want to explore space for that reason. The knowledge of it, as well, is particularly important for various kinds of missions including potential manned missions. It requires computational capability. It requires strength in material science and engineering. It requires strength in aerospace and thinking about new propulsion systems. You mentioned our having to use other people's rockets to get people to the International Space Station. We also use other people's rockets to launch our satellites and so that is an infrastructural question.

And then, you know, there is an overall question about overall industrial and manufacturing capacity to continue to make and develop these sorts of technologies, and I am sure Mr. Templeton can speak more directly to that, but these are areas that concern me as we go forward.

Mr. PALAZZO. Before I go to Dr. Vest, I do want to ask one more question because I know we are getting short on time. Dr. Jackson, does the space exploration, American space exploration, still excite children to study science, math, engineering and technology?

Dr. JACKSON. It sure does. We had a presentation at Rensselaer and it was during one of our alumni weekends of the landing of the Mars Rover, and that is because our Dean of Science, in fact, had two experiments on the Rover and was there the day the latest Rover landed. We also had some of the engineers in who were involved with the design and development of the latest Rover, and frankly, half the space, and we had it in a concert hall in our experimental media and performing arts center that holds about 1,200 people and half the people were young people and they were so excited. So absolutely, but I think it relates to Mr. Templeton's point that a big idea, something that we galvanize around, we rally around is really what captures people's imagination.

Mr. PALAZZO. Thank you.

Dr. VEST. I am going to speak out of both sides of my mouth, first by saying this generation has its own great challenges that it needs to be and is excited about, sustainability and energy security and resilience, provision of health care. It has got big challenges of its own that are even more important than the space race was, and we need to give some focus to that.

Having said that, I will admit I am a space cadet. I grew up in the 1950s and 1960s and lived through all this wonderful period. It is still—when we survey incoming freshmen at MIT, space is still the largest single motivator among these kids of why they went into science and engineering. That is the reason we need to keep at it.

But having said that, these programs are so big and so expensive that I think we need to find the right way to do them internationally. At one level it hurts me, but my logic, it doesn't bother me too much that at least for a period of time we are launching humans with a Russian rocket. We need this kind of synergy and integration. But I will tell you, nobody has done anything as exciting as this Mars lander. I mean, it was unbelievable.

And very quickly, you may know the story of the guy who managed the actual engineering of that project and that landing was a drop-out from high school who became a rock musician and eventually decided he wasn't going to make it with that and one night literally was driving home and looked up in the sky and saw Venus and he started thinking about this and he got more and more excited, and he said, you know, this is my destiny is to get out there somewhere, and I apologize for not having his name at my fingertips. He went back to community college, got a technology degree, started to work, eventually went to university and became an engineer and ran that project. You know, that is the kind of excitement we need, and we can kind of duplicate that with what we do in education. But I was very disappointed by the short time scale of America's attention to that program because I can't imagine anything more exciting. I have to——

Chairman SMITH. I am afraid to interrupt you all. Votes have been called and I am going to try to squeeze in one more Member to ask questions. Mr. Palazzo, thank you for your questions.

And also, let me sort of explain the situation to everyone who is here. The series of votes will mean we will not be able to come back for about an hour. Our Democratic friends are getting on buses immediately after these votes to go to an out-of-town retreat, and I am just wondering how many Members really would come back in an hour and if they might consider submitting questions in writing, and if that is not acceptable, we will come back, but if that is acceptable, I just apologize to you for not having time for Members. Does that sound all right? Okay. Thank you for your consideration.

The gentleman from California, Mr. Swalwell, is recognized for his questions.

Mr. SWALWELL. Thank you, Chairman Smith and Madam Ranking Member Johnson, and thank you, Mr. Templeton, Dr. Jackson and Dr. Vest.

We have talked a lot about startups today, and I am a startup Member of Congress, having just arrived here. I came to Congress wanting to support the innovation agenda, and as a freshman and a new Member in Congress, and a new Member to this Committee, I am encouraged that our first hearing is on research and development. I represent California's East Bay, where people understand that to do big things, you have to take big risks, and I am excited to be on this Committee because I truly do believe in science, and I believe in what science can do, and as our Ranking Member mentioned, the number of innovations that have come out of the Federal Government's role in science is very important to me.

I wanted to talk to you a little bit about Dr. Jackson and her testimony about collaboration between government and business and also Mr. Templeton discussed good examples of public R&D partnerships in the semiconductor industry. In Livermore, California, we have what is called IGATE, Innovation for Green Advanced Transportation Excellence. It is a regional public-private partnership designed to support small businesses and maximize the economic potential of green transportation and clean energy technologies. It is a partnership with the cities in the surrounding communities, Sandia and Lawrence Livermore National Laboratories and also the University of California, the Berkeley and Davis campuses.

And so my question is, we are just starting to see this project get off the ground, but as you can imagine, one of the biggest challenges is access to capital, to have an incubator-type setting where you can have small startups, medium-size startups come in and do the work that they need to do to create local made in America jobs. And so a couple questions. One, is there still a role for the Federal Government to play? Because I believe you need a federal partner if you are ever going to activate a region like that. Two, what can we do to increase access to capital as a Congress so that we can see those startups get going and create jobs? And three, how do we—and when we talk about the ecosystems of innovation, how do we also find those pipelines to the students where we have those businesses not just working on creating jobs but also transferring their knowledge to high school and college students who are going to be the next generation in those industries? So is there a role, how do we get the access to capital, how do we educate our children?

Dr. JACKSON. I will try to be succinct. I would say absolutely, there is a role. Now, we have talked about one element of that role having to do with support for basic research, support for students, both at the undergraduate level and importantly where we have not talked about it for graduate education and its linkage to research. But importantly, you mentioned energy, green energy technologies. Energy tends to be a huge kind of—there are any number of demonstration projects early in kinds of things people can do but it is the kind of activity that requires a certain degree of activity at scale, and so that kind of infrastructural support is very important, and the Federal Government can do any number of things, but one is simply to provide a safe harbor for corporate partners to come together, not unlike SEMATECH, to bring them together with universities, particularly in precompetitive research including applied research areas, to help support shared infrastructure and that is where smaller companies that really need to do prototyping. Some of the national labs are providing their major computational facilities to help companies with modeling and simulation, to be able to improve and begin to think about how to scale what they do. So it is kind of a daisy chain going from the fundamental research to creating the kind of safe harbors and partnerships that can allow roadmaps to be developed and people to move along, with the shared infrastructure as well. I am sure I have left something out, but these are some of the things that we try to do, and we don't have the benefit of being in Silicon Valley, we are in upstate New York, and so we don't have a big national lab. So the state has stepped in and done a lot of things, and then the universities themselves have come together. Thank you.

Mr. SWALWELL. Thank you. I yield back the balance of my time.

Chairman SMITH. Thank you. We have got about four minutes left to go vote. I thank you for yielding back.

Let me thank our witnesses today for their just wonderfully inspiring testimony. It has been very helpful, very informative, and I hope those who are watching this hearing either in person or on C–SPAN recognize that we are talking about a wonderful future for them and their children and grandchildren if we make the kind of investments in research and technology that we should. It is just going to pay a vast amount of rewards. It will improve productivity. It will improve people's standard of living, and that will benefit us all, but thank you all for your participation today.

[Whereupon, at 11:12 a.m., the Committee was adjourned.]

Appendix I

Answers to Post-Hearing Questions

ANSWERS TO POST-HEARING QUESTIONS

Responses by Mr. Richard Templeton

U.S. House Committee on Science, Space, and Technology
American Competitiveness: The Role of Research and Development
Response to Questions for the Record

Richard K. Templeton
Chairman, President and CEO
Texas Instruments

Honorable Randy Neugebauer (R-TX)

1. Do you think the government should prioritize funding basic, fundamental research over applied research?

Investing in basic research should clearly be a top priority for the federal government. Excluding the Recovery Act funding, federal agency investment in basic research has actually decreased 2.8% over the past decade in constant terms. (Source: American Association for the Advancement of Science)

That said, it should be noted that there is not a bright-line distinction between what is "basic" and what is "applied" research. The process of innovation is not always necessarily linear with basic research leading to applied research and then to technological development. In fact, basic research advances can and do often feed off, and depend on, advances in applied research. Thus, distinctions between "basic" and "applied" research are often very grey, at best.

Many agencies, such as DOD, DOE and NASA are specifically oriented towards supporting mission-oriented research for which trying to draw clear and distinct lines between basic and applied research can be difficult. In fact, there are many areas of long-term "use inspired" or mission-oriented research where government support may be crucial to the early development of particular technologies far before they are ready to be developed by the private market place. There are also areas of research that have high risk, high payoff potential in which private industry will not invest. The federal government has the resources and ability to be patient, which is what basic and certain applied research requires. No individual company has the resources to perform much of the research that the federal government underwrites.

2. Are you concerned about the government's potential ability to pick winners and losers in funding more applied research and development better suited to the private sector?

The government should not fund research that industry will readily fund. Industry does an enormous amount of research and development, and eclipses the R&D investment of the federal government. However, the reality is that most industry spending is on development, not research.

The assumption that applied research and development is better suited to the private sector does not take into account research challenges with real-world implications. Relevant examples of interest to the semiconductor industry might include areas such as medical applications, automotive safety, and security solutions, where the end use may be clear, but research and technical challenges remain, best solved in collaboration with universities and the federal government.

TI strongly supports the peer review process in funding both basic and applied research, as this allows funding to flow to the best ideas and avoids the possibility of political motives in "picking winners and losers."

The federal government should and can play a role in helping to foster strategic public-private partnerships and in supporting R&D efforts that are in our nation's best interests. The federal government has a long history of support not only for basic research, but also in high risk applied research programs and creative precompetitive ideas in order to nurture new technologies, technology platforms, drugs and vaccines that can then become the target of private research dollars.

Often this has been done when the government is both the supplier and user of the research in which it invests – such as national defense. In defense, the U.S. has a long history of supporting basic research, applied research and development. If it were not for those government investments, the U.S. might have missed critical and strategic opportunities to lead the world in critical areas of technology. Federal investments provided to SEMATECH during a period of extreme market uncertainty helped to ensure continued U.S. leadership in the semiconductor industry.

Even when the big industrial labs, such as Bell Labs, were engaged deeply in research, the federal government still needed to invest nearly $5B over 10 years to deliver the first prototype of a semiconductor diode. DOD funded this with a partnership between the government, university, and industry labs in order to ensure technical superiority in air missile technology. Bell Labs then invested an additional $25M – a very large investment from an individual company's perspective – to create the first commercial version that launched the IT revolution.

Another example is the Internet, which originated from research conducted at the Department of Defense and then the NSF, long before anyone ever imagined its commercial potential and before any private company had an interest in making such investments.

3. Would you agree that budget proposals from the Obama Administration – which are overwhelmingly focuses on late stage technology development – should be redirected to place a higher priority on basic research?

It is not clear which specific budget proposals are being referenced here, so it is difficult to comment. TI recognizes that in a tight fiscal climate trade-offs must be made, but these are choices for which we must prevail upon Congress to decide in light of the broader national perspective. Each program has to be carefully examined individually and assessed based upon a careful examination of various scientific and technological challenges, market forces, and national needs. As previously mentioned, a strong merit and peer review process is essential to funding the best R&D.

4. Do you support prioritizing basic research in the physical sciences over areas such as technology development and commercialization of new technologies?

Within basic research, TI certainly supports robust funding for the physical sciences and engineering, which have been declining as a percent of GDP since the 1970s. These are key disciplines for TI and the semiconductor industry. Support for basic research must be a top government priority. That being said, as noted above, the government does play a role in supporting high risk, high payoff research efforts and/or facilitating and nurturing the development of emerging technologies and technology platforms. As mentioned, Congress must weigh the trade-offs of where the funding goes, both within the R&D portfolio and broadly with other government programs.

5. How are these energy production driven (hydraulic fracking) spillover benefits affecting manufacturing facility operations or planning decisions at TI, its suppliers, or others in the semiconductor industry?

Energy is certainly a major cost in TI's manufacturing operations and a number of factors affect energy costs, not just supply. TI looks at a number of ways to reduce its energy costs, including renewable energy use.

Shale gas and slant drilling have reduced drilling costs – especially where they are also finding liquids – and have increased the supply of gas and increased reserves. Other factors, like the price of gas demand (including electric generation), amount of gas in storage, and short term effects from weather affect pricing as well.

Overall though, TI has benefited from lower gas prices primarily due to its impact on electricity prices over the past few years. This has made our U.S. factories more competitive.

Honorable Randy Hultgren (R-IL)

1. In what ways can we, policymakers on the Science Committee better tell the story of the role basic research plays in our lives?

The best examples are concrete, historical ones that relate to technologies used today, such as life-saving medical breakthroughs or personal technology devices that have their roots in government-funded research. For instance, technologies like the Internet, barcodes, fiber optics, speech recognition, magnetic resonance imaging (MRI), global positioning systems (GPS), lasers, data encryption, computer aided design (CAD), advanced sensors and the mouse are all items that affect nearly everyone on earth.

Members of the Science Committee should prioritize educating other Members of Congress and the public as to the tangible benefits of federal funding for basic science research. For example, briefings such as the "Deconstructing the iPad" organized by the Task Force on American Innovation and sponsored by you and other members can be an effective means to bring the value of basic research to life for lawmakers and their staff.

The FDA just approved retinal implants that allow the blind to see – this technology has its roots in university research at the University of Southern California. The effort had early and continuing support from NSF, the National Institutes of Health and the Department of Energy, with grants totaling more than $100 million, with nearly equal matching private sector support.

Paired with those historical examples, it is important to look forward at what is possible through research. Nanotechnology could have revolutionary applications in medicine, energy, electronics, security, and materials. Bioengineering is another example, where exciting developments at the intersection of electronics and medicine will literally change lives.

2. What effect do you think a lasting 4-5 year budget and appropriations certainty would have on American competitiveness?

Certainly, predictability and sustained, stable funding would benefit the R&D ecosystem. R&D is not a switch that can easily be turned off and on. Unpredictable funding streams make it particularly difficult for university professors and students to have the continuity with projects that breakthrough research requires. Even worse, sudden stops and starts in funding send a very strong negative signal to students about the future in that discipline, and could have the effect of discouraging the very STEM talent we are trying to nurture to benefit American competitiveness. If Congress were to adopt a longer-term budget and appropriations cycle, it would need to be flexible enough to be able to respond to new research priority areas.

Our U.S. research universities are the best in the world and attract the best students from around the world to study here. However, without the sustained robust funding for basic research done at U.S. universities, foreign researchers and even our own home grown future scientists will look to universities in countries that are making a strong investment in research.

As a result, the top talent educated abroad will end up working there for our foreign competitors and not for U.S. companies. Start up ventures and the jobs associated with this university research will be created overseas as will the corresponding IP and revenue. This is a no win situation for American competitiveness and our economy. It's imperative that we reverse this trend immediately.

Responses by Dr. Shirley Ann Jackson

Representative Randy Neugebauer (R-TX)

1. **Do you think the federal government should prioritize funding basic, fundamental research over applied research?**

   As was discussed during the hearing, the economic prosperity of our nation is linked directly to our nation's ability to generate scientific discoveries and technological innovations. These advances have sprung from both basic and applied research.

   In the extracellular matrix-based therapy example I described in my hearing testimony, the breakthrough did not come from just one scientific discipline or just one type of research. The breakthrough was made possible by research in the life sciences, chemical and biological engineering, nanotechnology, materials science, industrial engineering, space science, and earth and environmental science. In addition the success came about through a confluence of fundamental and applied science. Much of this work was appropriately funded by the Federal Government.

   I do agree that, in order to have a well-functioning innovation ecosystem, it is imperative to prioritize. As I stated in my testimony, one must have strategic focus. The possibilities for research are limitless, but funding is not. Therefore, it is important to choose carefully promising areas to explore and develop, and these must match the talent, resources, and opportunities that the U.S. has or can attract. Furthermore, our focus must be realistic with regard to timing. We cannot afford to be working on yesterday's challenges.

   The urgent global concerns that our nation faces in the 21st century- access to clean water, food security, energy security, environmental stewardship, health security, and disease mitigation- are some of the priority areas I would recommend.

2. **Are you concerned about the government's potential ability to pick winners and losers in funding more applied research and development better suited to the private sector?**

   There is broad agreement that the government should not pick winners and losers for specific commercial activities. However, as a nation we do have a vested interest in providing U.S. industries the tools to compete and thrive.

Emerging technologies in nanoelectronics or bioengineering may well demand the kind of computational power, instrumentation, robotics, and clean rooms that no single company can afford.

The Federal Government should begin to develop infrastructure that can be shared by nascent industries as a new kind of capital to undergird innovation. Such infrastructure could be based at universities or national laboratories or could be developed by industry with federal assistance.

There are examples of the Federal Government supporting pre-competitive private sector research. As I mentioned in the hearing, Sematech, the semiconductor consortium formed in 1987, with support from the U.S. Department of Defense, offers an interesting model. It was created to enable the development of manufacturing processes crucial to the industry that no single company could finance alone. It provided a "safe harbor" with respect to antitrust concerns. It allowed the companies to come together for pre-competitive research, sometimes in collaboration with universities. The consortium laid out a semiconductor research and development roadmap, which has been followed to position the U.S. as a leader in the semiconductor industry in advanced chip design and manufacturing. A combination of federal trade policy and funding, for efforts such as Sematech, has helped the semiconductor industry in the U.S. flourish.

3. **Would you agree that budget proposals from the Obama administration – which are overwhelmingly focused on late-stage technology development – should be redirected to place higher priority on basic research?**

To strengthen the economy, to address key global challenges, and to remain globally competitive, it will be essential for the U.S. government to sustain a comprehensive investment in a broad range of scientific research and development activities, with a primary focus on basic and early applied research.

The United States also has a vested interest in supporting advanced manufacturing and leading edge technologies. In most cases, that support comes through funding for basic and some early applied scientific research. Indeed, when one digs deep into the budgets of our federal civilian research agencies, a majority of their funding falls into these two categories. But in some *areas such as advanced manufacturing a more hands-on approach may be necessary.*

It is instructive to look at the ways research and development activities have changed, especially in light of more global competition for technological advantage. Countries such as Denmark, Finland, France, Iceland, Ireland, Japan, the Netherlands, New Zealand, Norway, South Korea, Spain, Sweden, Switzerland, and the United Kingdom all now have national agencies that specifically promote technological innovation in their domestic industries. These nations also fund basic research at research universities and national laboratories.

The President's Council of Advisors on Science and Technology used a definition of advanced manufacturing in our 2011 report, tilted, Ensuring American Leadership in Advanced Manufacturing, that I find useful: "advanced manufacturing, a family of activities that (a) depend on the use and coordination of information, automation, computation, software, sensing, and networking, and/or (b) make use of cutting edge materials and emerging capabilities enabled by the physical and biological sciences, for example nanotechnology, chemistry, and biology." Our nation's abilities to invent things and make things are inherently linked. The innovation ecosystem is not one-directional, especially with regard to advanced manufacturing. For example, what we learn through the process of making new materials advances new discoveries in basic science.

At its core our innovation ecosystem is based on discoveries in basic research, and this should remain the main focus of federal research dollars. However, in our globally competitive world we also need to be concerned about those translational pathways that bring discoveries to the commercial space in a more deliberate way than in the past. This will take more than just funding. Taxes, trade, intellectual property, education and training all play a part in the innovation ecosystem.

4. Do you support prioritizing basic research in the physical sciences over areas such as technology development and commercialization of new technologies?

Physical sciences are not inherently more or less valuable than the life sciences or the social sciences. Whether it is new approaches to energy generation and storage, the ability to fabricate new organs, planning for *disasters, advanced approaches to urban design, or space travel to Mars- these endeavors will require contributions from many disciplines.*

The 2012 National Research Council report Rising to the Challenge provides case studies on innovation policies in countries including China, India, Singapore, Taiwan, Germany, Japan and others. The report paints the vivid picture of other nations vigorously adopting policies and programs "to change the competitive landscape in their favor."

I would suggest that federal policymakers must expand the discussion beyond false choices among basic research, applied research, development, and commercialization. As I indicated in my previous answer, basic research remains a key driver to our innovation ecosystem. But funding for basic research alone will not be the only factor in helping the U.S. sustain the economy and retain its technological leadership.

Representative Randy Hultgren (R-IL)

1. **In what ways can we, as policy makers on the Science Committee, better tell the story of the role basic research plays in our lives?**

We see the influence of federally funded research every day in both big and small ways. One can pick up any major newspaper – or more likely these days read it online – and find examples of advanced technology in our lives front and center. But does the general public recognize the work behind these discoveries and innovations? Do you as Members of Congress celebrate the successes of science and engineering? Do you value the people doing this work?

It is a strange paradox that, in a nation whose economy so depends on scientific and technological progress, scientific illiteracy is common and acceptable. Many Americans have an easy intimacy with electronic devices, yet are at loose ends when asked to describe an integrated circuit or semiconductor.

We must evolve our national culture to celebrate not only the iPhone, the Kindle, and the handheld ultrasound, but also the spirit of inquiry, the discipline and focus, and the investment that yields such devices. Teachers alone cannot effect such a change. Scientists, engineers, mathematicians, executives, and *entrepreneurs must find a way to communicate the joyous aspects of their work to the young — and the simple truth that America's future depends on its ability to innovate.*

As Members of Congress you have a public platform to promote science, to celebrate its successes and the scientists and engineers who do the work. Visit classrooms and lab in K-12 schools and colleges and universities in your districts, talk to scientific entrepreneurs, start a science section on your Congressional websites (as Congressman Hultgren has suggested). As elected officials, you have the opportunity to use your positions to influence minds, use that influence in a positive way to promote all of the STEM disciplines.

2. **What effect do you think lasting 4-5 year budget and appropriations certainty would have on American competitiveness?**

The Mars Rovers, Hubble Space Telescope, Large Hadron Collider, and the Human Genome Project were all massive multi-year scientific projects that have captured imaginations, and are helping humanity make great leaps in our scientific knowledge. The U.S. scientific enterprise could certainly benefit from multi -year certainty in federal budgeting and appropriations, especially for such large multi-year projects. Yearly budget uncertainty causes significant and sometimes costly difficulties in construction and personnel disruptions.

Even without longer term appropriations, Congress and the Executive Branch could do more to increase sustainability and predictability of federal research funding. Examining the example of NIH, its appropriations doubled between 1998 and 2003, then declined 11.6 percent in real (inflation-adjusted) dollars over the next five years. In 2009-2010 the NIH received a temporary increase from the American Recovery and Reinvestment Act, but then continued to decline. This kind of roller coaster budgeting can cause disruptions when research is a long term endeavor. Steadier, less volatile long –term funding for science should be a goal shared by both budgeting branches of the Federal Government.

If the United States does not want to lose its technological leadership to our competitors, we must make the long term strategic investments to maintain and build our national capacity to do so.

Responses by Dr. Charles Vest

QUESTIONS FOR THE RECORD
THE HONORABLE RANDY NEUGEBAUER (R-TX)
U.S. House Committee on Science, Space, and Technology

American Competitiveness: The Role of Research and Development

Friday, February 6, 2013

1. *Do you think the federal government should prioritize funding basic, fundamental research over applied research?*

   External funding to universities and independent laboratories must include a substantial portion of truly basic research, our ultimate "seed corn." However, in the 21st century the line between "basic" and applied" research is very fuzzy, and some of the most productive research can be thought of as "use-inspired basic research." In my opinion, the best way to sort this out is through strong merit-based award processes, because this creates a marketplace of ideas in which the best will be funded.

2. *Are you concerned about the government's ability to pick winners and losers in funding more applied research and development better suited to the private sector?*

   Market-facing industry will make the best decisions in highly applied research and product development. Today, universities and independent laboratories should – and generally do - focus on those areas that the private sector does not support, usually because the time horizons to commercialization are too long, or because individual companies do not believe that they will reap the primary benefits of the work.

3. *Would you agree that budget proposals from the Obama Administration – which are overwhelmingly focused on late-stage technology development – should be redirected to place a higher priority on basic research?*

   Basic research should be the highest priority for federal funding of research in universities and independent laboratories. Having said this, I do support efforts such as ARPA-E that focuses on clear national need and brings new players such as universities and young entrepreneurial companies to the table in high-risk, high-payoff research, most of which fits the "use-inspired basic research" category, and prepares promising technologies to move into the private sector.

4. *Do you support prioritizing basic research in the physical sciences over areas such as technology development and commercialization of new technologies?*

   Basic research should be the highest priority for funding of universities and independent laboratories.

QUESTIONS FOR THE RECORD
THE HONORABLE RANDY HULTGREN (R-IL)
U.S. House Committee on Science, Space, and Technology

American Competitiveness: The Role of Research and Development

Friday, February 6, 2013

1. In what ways can we, as policy makers on the Science Committee, better tell the story of the role basic research plays in our lives?

   I know that as members of Congress, you have many issues to balance, but I believe that if you could simply work to get your colleagues outside the committee to recognize that without basic research, our economic system will run out of steam, it would be enormously helpful. I also respectfully suggest that simply mentioning this routinely, in your speeches to constituents and discussions with journalists, it would go a long way. As you well know, making this point with specific, human and business examples of success, especially from your districts, is very effective. I am certain that the science and engineering communities, and key faculty in universities in your districts or states would be more than
   happy to assist in suggesting great examples.

2. What effect do you think that certainty of a 4 or 5-year budget and appropriations process would have on American competitiveness?

   Individual researchers and research groups strongly value the ability to plan with some certainty for a multi-year period. They also spend far too much time writing numerous proposals for short-term funding - time that would better be spent in research and teaching. To the extent that a longer budget and appropriations process would enhance this, efficiency would be increased and it should be seriously considered in my opinion.