Testimony of

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

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"American Competitiveness: The Role of Research and Development"

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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 <u>basics</u>, 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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