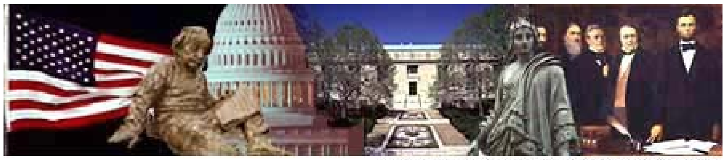
Mailing Address:
The Office of Congressional and Public Affairs
The National Academies
Room NAS 220
2101 Consitution Avenue NW
Washington, DC 20418
Tel: (202) 334-1601
Fax: (202) 334-2419



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For Congress

Date:	10/20/2005
Session:	109th Congress (First Session)
Witness(es):	Norman R. Augustine, P. Roy Vagelos, and William A. Wulf
Credentials:	**Norman R. Augustine**, Retired Chairman and Chief Executive Officer, Lockheed Martin Corporation and Chair, Committee on Prospering in the Global Economy of the 21st Century, Committee on Science, Engineering, and Public Policy, Division on Policy and Global Affairs, The National Academies **P. Roy Vagelos, M.D.**, Retired Chairman and Chief Executive Officer, Merck & Co., Inc. and Member, Committee on Prospering in the Global Economy of the 21st Century, Committee on Science, Engineering, and Public Policy, Division on Policy and Global Affairs, The National Academies **William A. Wulf, Ph.D.**, President, National Academy of Engineering, The National Academies
Chamber:	House
Committee:	Science Committee, U.S. House of Representatives
Subject:	Science, Technology, and Global Economic Competitiveness

(PLEASE NOTE: The statements of the three witnesses follow in the order listed above.)

Rising Above The Gathering Storm: Energizing and Employing America for a Brighter Economic Future

Statement of

Norman R. Augustine
Retired Chairman and Chief Executive Officer
Lockheed Martin Corporation

And

Chair, Committee on Prospering in the Global Economy of the 21st Century
Committee on Science, Engineering, and Public Policy
Division on Policy and Global Affairs
The National Academies

before the

Committee on Science
U.S. House of Representatives

October 20, 2005

Mr. Chairman and members of the Committee.

Thank you for this opportunity to appear before you on behalf of the National Academies' Committee on

Prospering in the Global Economy of the 21st Century. As you know, our effort was sponsored by the National Academy of Sciences, National Academy of Engineering and Institute of Medicine (collectively known as the National Academies). The National Academies were chartered by Congress in 1863 to advise the government on matters of science and technology.

The Academies were requested by Senator Alexander and Senator Jeff Bingaman, members of the Senate Committee on Energy and Natural Resources to conduct an assessment of America's ability to compete and prosper in the 21st century—and to propose appropriate actions to enhance the likelihood of success in that endeavor. This request was endorsed by Representatives Sherwood Boehlert and Bart Gordon of the House Committee on Science.

To respond to that request the Academies assembled twenty individuals with diverse backgrounds, including university presidents, CEOs, Nobel Laureates and former presidential appointees. The result of our committee's work was examined by over forty highly qualified reviewers who were also designated by the Academies. In undertaking our assignment we considered the results of a number of prior studies which were conducted on various aspects of America's future prosperity. We also gathered sixty subject-matter experts with whom we consulted for a weekend here in Washington and who provided recommendations related to their fields of specialty.

It is the unanimous view of our committee that America today faces a serious and intensifying challenge with regard to its future competitiveness and standard of living. Further, we appear to be on a losing path. We are here today hoping both to elevate the nation's awareness of this developing situation and to propose constructive solutions.

The thrust of our findings is straightforward. The standard of living of Americans in the years ahead will depend to a very large degree on the quality of the jobs that they are able to hold. Without quality jobs our citizens will not have the purchasing power to support the standard of living which they seek, and to which many have become accustomed; tax revenues will not be generated to provide for strong national security and healthcare; and the lack of a vibrant domestic consumer market will provide a *disincentive* for either U.S. or foreign companies to invest in jobs in America.

What has brought about the current situation? The answer is that the prosperity equation has a new ingredient, an ingredient that some have referred to as "The Death of Distance". In the last century, breakthroughs in aviation created the opportunity to move people and goods rapidly and efficiently over very great distances. Bill Gates has referred to aviation as the "World Wide Web of the twentieth century". In the early part of the present century, we are approaching the point where the communication, storage and processing of information are nearly free. That is, we can now move not only physical items efficiently over great distances, we can also transport *information* in large volumes and at little cost.

The consequences of these developments are profound. Soon, only those jobs that require near-physical contact among the parties to a transaction will not be opened for competition from job seekers around the world. Further, with the end of the Cold War and the evaporation of many of the political barriers that previously existed throughout the world, nearly three *billion* new, highly motivated, often well educated, new capitalists entered the job market.

Suddenly, Americans find themselves in competition for their jobs not just with their neighbors but with individuals around the world. The impact of this was initially felt in manufacturing, but soon extended to the development of software and the conduct of design activities. Next to be affected were administrative and support services. Today, "high end" jobs, such as professional services, research and management, are impacted. In short, few jobs seem "safe":

- U.S. companies each morning receive software that was written in India overnight in time to be tested in the U.S. and returned to India for further production that same evening—making the 24-hour workday a practicality.
- Back-offices of U.S. firms operate in such places as Costa Rica, Ireland and Switzerland.
- Drawings for American architectural firms are produced in Brazil.
- U.S. firm's call centers are based in India—where employees are now being taught to speak with a mid-western accent.
- U.S. hospitals have x-rays and CAT scans read by radiologists in Australia and India.

• At some McDonald's drive-in windows orders are transmitted to a processing center a thousand miles away (currently in the U.S.), where they are processed and returned to the worker who actually prepares the order.

• Accounting firms in the U.S. have clients tax returns prepared by experts in India.

• Visitors to an office not far from the White House are greeted by a receptionist on a flat screen display who controls access to the building and arranges contacts—she is in Pakistan.

• Surgeons sit on the opposite side of the operating room and control robots which perform the procedures. It is not a huge leap of imagination to have highly-specialized, world-class surgeons located not just across the operating room but across the ocean.

As Tom Friedman concluded in *The World is Flat*, globalization has "accidentally made Beijing, Bangalore and Bethesda next door neighbors". And the neighborhood is one wherein candidates for many jobs which currently reside in the U.S. are now just a "mouse-click" away.

How will America compete in this rough and tumble global environment that is approaching faster than many had expected? The answer appears to be, "not very well"—unless we do a number of things differently from the way we have been doing them in the past.

Why do we reach this conclusion? One need only examine the principal ingredients of competitiveness to discern that not only is the world flat, but in fact it may be tipping *against* us.

One major element of competitiveness is, of course, the cost of labor. I recently traveled to Vietnam, where the wrap rate for low-skilled workers is about twenty-five cents per hour, about one-twentieth of the U.S. minimum wage. And the problem is not confined to the so-called "lower-end" of the employment spectrum. For example, five qualified chemists can be hired in India for the cost of just one in America. Given such enormous disadvantages in labor cost, we cannot be satisfied merely to match other economies in those other areas where we do enjoy strength; rather we must excel . . . markedly.

The existence of a vibrant domestic market for products and services is another important factor in determining our nation's competitiveness, since such a market helps attract business to our shores. But here, too, there are warning signs: Goldman Sachs analysts project that within about a decade, fully 80% of the world's *middle-income* consumers will live in nations outside the currently industrialized world.

The availability of financial capital has in the past represented a significant competitive advantage for America. But the mobility of financial capital is legion, as evidenced by the willingness of U.S. firms to move factories to Mexico, Vietnam and China if a competitive advantage can be derived by doing so. Capital, as we have observed, crosses geopolitical borders at the speed of light.

Human capital—the quality of our work force—is a particularly important factor in our competitiveness. Our public school system comprises the foundation of this asset. But as it exists today, that system compares, in the aggregate, abysmally with those of other developed—and even developing—nations . . . particularly in the fields which underpin most innovation: science, mathematics and technology.

Of the utmost importance to competitiveness is the availability of knowledge capital—"ideas". And once again, scientific research and engineering applications are crucial. But knowledge capital, like financial capital, is highly mobile. There *is* one major difference: being first-to-market, by virtue of access to new knowledge, can be immensely valuable, even if by only a few months. Craig Barrett, a member of our committee and Chairman of Intel, points out that ninety percent of the products his company delivers on December 31st did not even exist on January 1st of that same year. Such is the dependence of hi-tech firms on being at the leading edge of scientific and technological progress.

There are of course many other factors influencing our nation's competitiveness. These include patent processes, tax policy and overhead costs—such as healthcare, regulation and litigation—all of which tend to work against us today. On the other hand, America's version of the Free Enterprise System has proven to be a powerful asset, with its inherent aggressiveness and discipline in introducing new ideas and flushing out the obsolescent. But others have now recognized these virtues and are seeking to emulate our system.

But is it not a *good* thing that others are prospering? Our committee's answer to that question is a resounding *"yes"*. Broadly based prosperity can make the world more stable and safer for all; it can make less costly products available for American consumers; it can provide new customers for the products we produce here. Yet it is inevitable that there will be relative winners and relative losers—and as the world prospers, we should seek to assure that America does not fall behind in the race.

The enigma is that in spite of all these factors, America seems to be doing quite well just now. Our nation has the highest R&D investment intensity in the world. We have indisputably the finest research universities in the world. California alone has more venture capital than any nation in the world other than the United States. Two million jobs were created in America in the past year alone, and citizens of other nations continue to invest their savings in America at a remarkable rate. Total household net worth is now approaching $50 *trillion*.

The reason for this prosperity is that we are reaping the benefits of past investments—many of them in the fields of science and technology. But the early indicators of future prosperity are generally heading in the wrong direction. Consider the following:

• For the cost of one engineer in the United States, a company can hire eleven in India.

• America has been depending heavily on foreign-born talent. Thirty-eight percent of the scientists and engineers in America holding doctorates were born abroad. Yet, when asked in the spring of 2005, what are the most attractive places in the world in which to live, respondents in only one of the countries polled indicated the U.S.A.

• Chemical companies closed seventy facilities in the U.S. in 2004, and have tagged forty more for shutdown. Of 120 *new* chemical plants being built around the world with price tags of $1 billion or more, one is in the U.S. Fifty are in China.

• In 1997 China had fewer than fifty research centers managed by multinational corporations. By 2004 there were over six-hundred.

• Two years from now, for the first time, the most capable high-energy particle accelerator on earth will reside outside the United States.

• The United States today is a net importer of *high technology* products. The U.S. share of global high tech exports has fallen in the last two decades from 30% to 17%, while America's trade balance in high tech manufactured goods shifted from a *positive* $33B in 1990 to a *negative* $24B in 2004.

• In a recent international test involving mathematical understanding, U.S. students finished in 27th place among the nations participating.

• About two-thirds of the students studying chemistry and physics in U.S. high schools are taught by teachers with no major or certificate in the subject. In the case of math taught in grades five through twelve, the fraction is one-half. Many such students are being taught math by graduates in physical education.

• In one recent period, low-wage employers like Wal-Mart (now the nation's largest employer) and McDonald's created 44% of all new jobs. High-wage employers created only 29%.

• In 2003 foreign students earned 59% of the engineering doctorates awarded in U.S. universities.

• In 2003 only three American companies ranked among the top ten recipients of patents granted by the *U.S.* Patent Office.

• In Germany, 36% of undergraduates receive their degrees in science and engineering. In China, the corresponding figure is 59%, and in Japan it is 66%. In the U.S., the share is 32%. In the case of engineering, the U.S. share is 5%, as compared with 50% in China.

• The United States is said to have over ten million illegal immigrants, but the number of legal visas set-aside annually for "highly qualified foreign workers" was recently dropped from 195,000 per year down to 65,000.

• At a time when the world's nations are clamoring to obtain science and engineering talent, U.S. law will grant a visa for outstanding foreign students to attend U.S. universities only if they promise they will go home when they graduate.

• In 2001 (the most recent year for which data are available), U.S. industry spent more on tort litigation and related costs than on research and development.

As important as jobs are, the impact of these circumstances on our nation's security could be even more profound. In the view of the bipartisan Hart-Rudman Commission on National Security, ". . . the inadequacies of our system of research and education pose a greater threat to U.S. national security over the next quarter century than any potential conventional war that we might imagine."

The good news is that there are things we can do to assure that America does in fact share in the prosperity that science and technology are bringing the world. In this regard, our committee has made four broad recommendations as the basis of a prosperity initiative—and offers 20 specific actions to make these recommendations a reality. They include:

o "Ten Thousand Teachers, Ten Million Minds"—which addresses America's K-12 education system. We recommend that America's talent pool in science, math and technology be increased by vastly improving K-12 education. Among the specific steps we propose are:

• Recruitment of 10,000 new science and math teachers each year through the award of competitive scholarships in math, science and engineering that lead to a bachelor's degree accompanied by a *teaching certificate*—and a 5-year commitment to teach in a public school.

• Strengthening the skills of 250,000 current teachers through funded training and education in part-time master's programs, summer institutes and Advanced Placement training programs.

• Increasing the number of students who take Advanced Placement science and mathematics courses.

o "Sowing the Seeds"—which addresses America's research base. We recommend strengthening the nation's traditional commitment to long-term *basic* research through:

• Increasing federal investment in research by 10% per year over the next seven years, with primary attention devoted to the physical sciences, engineering, mathematics, and information sciences—without *dis*investing in the health and biological sciences.

• Providing research grants to early career researchers

• Instituting a National Coordination Office for Research Infrastructure to oversee the investment of an additional $500M per year for five years for advanced research facilities and equipment.

• Allocating at least 8% of the existing budgets of federal research agencies to discretionary funding under the control of local laboratory directors.

• Creation of an Advanced Research Projects Agency—Energy (ARPA-E), modeled after DARPA in the Department of Defense, reporting to the Department of Energy Undersecretary for Science. The purpose is to support the conduct of out-of-the-box, transformational, generic, energy research by universities, industry and government laboratories.

• Establish a Presidential Innovation Award to recognize and stimulate scientific and engineering advances in the national interest.

o "Best and Brightest"—which addresses higher education. In this area we recommend:

• Establishing 25,000 competitive science, mathematics, engineering, and technology undergraduate scholarships and 5,000 graduate fellowships in areas of national need for US citizens pursuing study at US universities.

• Providing a federal tax credit to employers to encourage their support of continuing education.

• Providing a one-year automatic visa extension to international students who receive a science or engineering doctorate at a U.S. university, and providing automatic work permits and expedited residence status if these students are offered employment in the US.

• Instituting a skill-based, preferential immigration option

• Reforming the current system of "deemed exports" so that international students and researchers have access to necessary non-classified information or research equipment while studying and working in the US.

o "Incentives for Innovation"—in which we address the innovation environment itself. We recommend:

• Enhancements to intellectual property protection, such as the adoption of a first-to-file system.

• Increasing the R&D tax credit from the current 20% to 40%, and making the credit permanent.

• Providing permanent tax incentives for US-based innovation so that the United States is one of the most attractive places in the world for long-term innovation-related investments.

• Ensuring ubiquitous broadband Internet access to enable U.S. firms and researchers to operate at the state of the art in this important technology.

It should be noted that we are not confronting a so-called "typical" crisis, in the sense that there is no 9/11, Sputnik or Pearl Harbor to alert us as a nation. Our situation is more akin to that of the proverbial frog being slowly boiled. Nonetheless, while our committee believes the problem we confront is both real and serious, the good news is that we may well have time to do something about it—if we start now.

Americans, with only 5% of the world's population but with nearly 30% of the world's wealth, tend to believe that scientific and technological leadership and the high standard of living it underpins is somehow the natural state of affairs. But such good fortune is *not* a birthright. If we wish our children and grandchildren to enjoy the standard of living most Americans have come to expect, there is only one answer: We must get out and *compete*.

I would like to close my remarks with a perceptive and very relevant poem. It was written by Richard Hodgetts, and eloquently summarizes the essence of innovation in the highly competitive, global environment. The poem goes as follows:

Every morning in Africa a gazelle wakes up.
It knows it must outrun the fastest lion or it will be killed.

Every morning in Africa a lion wakes up.
It knows it must outrun the slowest gazelle or it will starve.

It doesn't matter whether you're a lion or a gazelle –
when the sun comes up, you'd better be running.

And indeed we should.

Thank you for providing me with this opportunity to testify before the committee. I would be pleased to answer any questions you have about the report.

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RESPONSE TO HOUSE COMMITTEE ON SCIENCE QUESTIONS

1. How did the study panel arrive at the recommended 10 percent annual increase in federally-sponsored basic research over the next seven years? What other options did the panel consider and what led to the choice of 10 percent?

After reviewing the proposals for enhanced research funding that have been made in recent years, the committee concluded that a 10% annual increase over a 7-year period would be appropriate. This achieves the doubling that was in principle part of the NSF Authorization Act of 2002 approved by Congress and the President, but would expand it to other agencies and focus that increase on the physical sciences, engineering, mathematics, and the information sciences as well as DOD basic research.

The committee viewed enhanced funding in these fields as urgent. It chose the 10 percent level and 7 year time frame as the best way for these funds to be spent effectively. The base for this doubling (federal funding for the fields listed plus DOD basic research—not including the specified fields so there is no double-counting) was approximately $8 billion in FY 2004.

By taking this action, the balance of the nation's research portfolio in fields that are essential to the generation of both ideas and skilled people for the nation's economy and national/homeland security would be restored. That does not mean that there should be a *disinvestment* in such important fields as the life sciences (which have in fact seen growth in recent years) or the social sciences. A balanced research portfolio in all fields of science and engineering research is critical to US prosperity.

As indicated in the National Academies Committee on Science, Engineering, and Public Policy's (COSEPUP) 1993 report *Science, Technology, and the Federal Government: National Goals for a New Era*

The United States needs to be among the world leaders in all fields of research so that it can

- Bring the best available knowledge to bear on problems related to national objectives even if that knowledge appears unexpectedly in a field not traditionally linked to that objective.

- Quickly recognize, extend, and use important research results that occur elsewhere;

- Prepare students in American colleges and universities to become leaders themselves and to extend and apply the frontiers of knowledge.

- Attract the brightest young students.[1]

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1. COSEPUP. 1993. *Science, Technology, and the Federal Government: National Goals for a New Era.* Washington, DC: National Academy Press.

2. How did the study panel arrive at the recommended 8 percent allocation within each federal research agency's budget to be managed at the discretion of technical program managers to catalyze high-risk, high-payoff research? What other options did the panel consider and what led to the choice of 8 percent?

The committee found that at many agencies approximately 1 to 3 percent of a program's budget is to be managed at the discretion of the program managers. The committee believes, as shown through the Defense Advanced Research Projects Agency (DARPA) model, that more risky research that crosses disciplinary lines can be funded by using the "strong program manager" approach as is the case at DARPA. Some committee members believed that 5% was sufficient, others 10%—in the end a compromise was reached at 8%. The committee is flexible about the specific number as long as the goal of catalyzing high-risk, high-payoff research (as opposed to incremental research) is achieved. Experience shows that research investments of this type are exceptionally highly leveraged.

3. Industry and government have both developed numerous energy production and energy efficiency technologies that have not been deployed. How did the study panel arrive at its implicit conclusion that technology development is the greater bottleneck (as opposed to policy) in developing energy systems for a 21st century economy?

The committee believes that both policy and technology play a role in responding to the nation's need for clean, affordable, and reliable energy.

While the implementation of some technologies, such as nuclear energy, is discouraged by policy, we still face environmental and safety challenges only science and engineering research can ameliorate—even if policymakers were willing to deploy that technology today. There are no doubt questions of cost and policy that affect use of various energy technologies. When was the last nuclear plant commissioned? But those policy decisions are often directly linked to technical capabilities or the absence thereof. No 'final' solutions without serious problems are waiting in the wings for policy changes. Nuclear energy is an (the) important potential source of energy but it has security and waste disposal/storage problems that have not been handled satisfactorily. That is a prime example of a policy problem that requires research to unlock it.

Similarly, the nation, as the report indicates, has made substantial strides in efficiency, but much more can be done. Yes there is existing efficiency technology that can be deployed, and, following market forces if oil prices do not return to recent levels will probably be used increasingly.

As a result, the nation will not significantly decrease energy dependence without technology—policy changes alone are insufficient. The production of electricity and mobility on a world wide basis cannot go on for ever in their present form. This country is running a significant risk of remaining substantially dependent on foreign oil.

The history of science and technology suggests that radical new solutions may well be available. The field of energy has not been viewed as exciting by a generation of engineering students. The time required to effect an energy solution from research to implementation is considerable. The rate of growth of the energy problem (usage) worldwide is likely to have profound effects.

We believe that the Advanced Research Projects Agency (ARPA-E) proposed by the committee can jump start new approaches to high risk / high payoff research of the type that DARPA has historically performed to great effect for the military. It can capture the talents of outstanding young people in industry and academia. DARPA is a demonstrably effective approach to advanced research and development, and Energy is one of the most important challenges to our nation's future.

4. Recent surveys of industry suggest that basic research performed at universities and transformational technological innovation have only a very limited impact on the success of individual companies. Is the impact of research and innovation different for the economy as a whole than it is for individual companies?

There is broad consensus among economists that for decades the growth of the U.S. economy has been driven by technological advances and innovation. These come almost exclusively from two sources -- companies and universities. Companies are devoting fewer and fewer resources to longer-term research that contributes to the common base of technology that is available to all; i.e. work that improves our national capacity but doesn't necessarily directly drive that company's profits. Universities are increasingly the only avenue for the research that will lead to fundamentally new things and to a highly-educated workforce. Most large companies now strive for a large percentage of their products to have been developed within the last two or three years. This requires constant and focused innovation. The immediate crowds out the strategic.

Truly transformational technologies do not come along every day, and cannot be readily predicted. But one thing is certain - if we do not invest in research and advanced training for scientists and engineers, they will not occur at all - at least not in the United States.

Because of this, the committee disagrees with the first premise in the question. Industry gains not only from the new knowledge generated as a result of academic research, but also from the skilled people generated as a result of research.

Although many industries as diverse as the pharmaceutical and banking industry understand the linkage of their business to science and technology, others do not always fully understand the linkages between its day-to-day activities and science and technology. For example, at one point, we thought that the trucking industry was not particularly sensitive to science and technology. But the trucking industry certainly has been able to enhance its competitiveness by using tools such as the global positioning system, advanced lightweight materials, the ability to use the internet, and weather forecasting to enhance its ability to locate the best route to a destination thus lowering its operating cost. In addition, its competitiveness could be enhanced further if new ways are developed for the industry to be more efficient in its use of fuel and if more affordable fuels are developed.

As a result, when looking at its primary operations, a single company may not see direct use of basic research if it has not licensed a patent, contracted for studies or undertaken its own work. But slightly below the surface the substantial contribution of basic research to essentially every company is evident.

For some industries, research provides them with the talented people they need whose education is influenced in substance, thinking and methods by basic research experience/training. Talented graduates for corporate laboratories are a primary deliverable of basic research operations at universities. Many major companies, in addition, support basic research at universities first and foremost to gain access to these people.

Secondly, essentially every company buys technology whose function and cost are controlled by basic research conducted earlier. So companies that assemble products using others' components may not be involved in basic research directly but their business remains dependent on the basic research behind the component technologies that they use.

Third, basic research creates the new technologies and new enterprises that these companies will sell to, or buy from or even become. Frankly, it is difficult to think of a company that does not use technology at some level, and that technology evolved from basic research.

Fourth, the people generated as a result of the higher education they receive, underpinned by basic research, create whole new industries and jobs. For example, in 1997, BankBoston conducted the first national study of the economic impact of a research university. It found that graduates of the Massachusetts Institute of Technology founded 4,000 firms which, in 1994 alone, employed at least 1.1 million people and generated $232 billion of world sales. Further, if the companies founded by MIT graduates and faculty formed an independent nation, the revenues produced by the companies would make that nation the 24th largest economy in the world. Within the United States, the companies founded by MIT graduates employed a total of 733,000 people in 1994 at more than 8,500 plants and offices in the 50 states- equal to one out of every 170 jobs in America. Eighty percent of the jobs in the MIT-related firms are in manufacturing (compared to 16 percent nationally), and a high percentage of products are exported.

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COMMITTEE ON PROSPERING IN THE GLOBAL ECONOMY OF THE 21ST CENTURY

BIOGRAPHIC INFORMATION

NORMAN R. AUGUSTINE [NAE*] (Chair) is the retired chairman and CEO of the Lockheed Martin Corporation. He serves on the President's Council of Advisors on Science and Technology and has served as undersecretary of the Army. He is a recipient of the National Medal of Technology.

CRAIG BARRETT [NAE] is chairman of the Board of the Intel Corporation.

GAIL CASSELL [IOM*] is vice president for scientific affairs and a Distinguished Lilly Research Scholar for Infectious Diseases at Eli Lilly and Company.

STEVEN CHU [NAS*] is the director of the E.O. Lawrence Berkeley National Laboratory. He was a cowinner of the Nobel prize in physics in 1997.

ROBERT GATES is the president of Texas A&M University and served as Director of Central Intelligence.

NANCY GRASMICK is the Maryland state superintendent of schools.

CHARLES HOLLIDAY JR. [NAE] is chairman of the Board and CEO of DuPont.

SHIRLEY ANN JACKSON [NAE] is president of Rensselaer Polytechnic Institute. She is the immediate past president of the American Association for the Advancement of Science and was chairman of the US Nuclear Regulatory Commission.

ANITA K. JONES [NAE] is the Lawrence R. Quarles Professor of Engineering and Applied Science at the University of Virginia. She served as director of defense research and engineering at the US Department of Defense and was vice-chair of the National Science Board.

JOSHUA LEDERBERG [NAS/IOM] is the Sackler Foundation Scholar at Rockefeller University in New York. He was a cowinner of the Nobel prize in physiology or medicine in 1958.

RICHARD LEVIN is president of Yale University and the Frederick William Beinecke Professor of Economics.

C. D. (DAN) MOTE JR. [NAE] is president of the University of Maryland and the Glenn L. Martin Institute Professor of Engineering.

CHERRY MURRAY [NAS/NAE] is the deputy director for science and technology at Lawrence Livermore National Laboratory. She was formerly the senior vice president at Bell Labs, Lucent Technologies.

PETER O'DONNELL JR. is president of the O'Donnell Foundation of Dallas, a private foundation that develops and funds model programs designed to strengthen engineering and science education and research.

LEE R. RAYMOND [NAE] is the chairman of the Board and CEO of Exxon Mobil Corporation.

ROBERT C. RICHARDSON [NAS] is the F. R. Newman Professor of Physics and the vice provost for research at Cornell University. He was a cowinner of the Nobel prize in physics in 1996.

P. ROY VAGELOS [NAS/IOM] is the retired chairman and CEO of Merck & Co., Inc. He serves as chairman of New Jersey's Commission on Jobs, Growth, and Economic Development.

CHARLES M. VEST [NAE] is president emeritus of MIT and a professor of mechanical engineering. He serves on the President's Council of Advisors on Science and Technology and is the immediate past chair of the Association of American Universities.

GEORGE M. WHITESIDES [NAS/NAE] is the Woodford L. & Ann A. Flowers University Professor at Harvard University. He has served as an adviser for the National Science Foundation and the Defense Advanced Research Projects Agency.

RICHARD N. ZARE [NAS] is the Marguerite Blake Wilbur Professor of Natural Science at Stanford University. He was chair of the National Science Board from 1996 to 1998.

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BIOGRAPHICAL SKETCH OF NORMAN R. AUGUSTINE

NORMAN R. AUGUSTINE was raised in Colorado and attended Princeton University where he graduated with a BSE in Aeronautical Engineering, magna cum laude, an MSE and was elected to Phi Beta Kappa, Tau Beta Pi and Sigma Xi.

In 1958 he joined the Douglas Aircraft Company in California where he held titles of Program Manager and Chief Engineer. Beginning in 1965, he served in the Pentagon in the Office of the Secretary of Defense as an Assistant Director of Defense Research and Engineering. Joining the LTV Missiles and Space Company in 1970, he served as Vice President, Advanced Programs and Marketing. In 1973 he returned to government as Assistant Secretary of the Army and in 1975 as Under Secretary of the Army and later as Acting Secretary of the Army. Joining Martin Marietta Corporation in 1977, he served as Chairman and CEO from 1988 and 1987, respectively, until 1995, having previously been President and Chief Operating Officer. He served as President of Lockheed Martin Corporation upon the formation of that company in 1995, and became its Chief Executive Officer on January 1, 1996, and later Chairman. Retiring as an employee of Lockheed Martin in August, 1997, he joined the faculty of the Princeton University School of Engineering and Applied Science where he served as Lecturer with the Rank of Professor until July, 1999.

Mr. Augustine served as Chairman and Principal Officer of the American Red Cross for nine years and as Chairman of the National Academy of Engineering, the Association of the United States Army, the Aerospace Industry Association, and the Defense Science Board. He is a former President of the American Institute of Aeronautics and Astronautics and the Boy Scouts of America. He is currently a member of the Board of Directors of ConocoPhillips, Black & Decker and Procter & Gamble and a member of the Board of Trustees of Colonial Williamsburg and Johns Hopkins and a former member of the Board of Trustees of Princeton and MIT. He is a member of the President's Council of Advisors on Science and Technology and the Department of Homeland Security Advisory Board and was a member of the Hart/Rudman Commission on National Security.

Mr. Augustine has been presented the National Medal of Technology by the President of the United States and has five times been awarded the Department of Defense's highest civilian decoration, the Distinguished Service Medal and has received the Joint Chiefs of Staff Distinguished Public Service Award. He is co-author of *The Defense Revolution* and *Shakespeare In Charge* and author of *Augustine's Laws* and *Augustine's Travels*. He holds eighteen honorary degrees and was selected by Who's Who in America and the Library of Congress as one of the Fifty Great Americans on the occasion of Who's Who's fiftieth anniversary. He has traveled in nearly 100 countries and stood on both the North and South Poles.

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Rising Above The Gathering Storm:
Energizing and Employing America for a Brighter Economic Future

Statement of

P. Roy Vagelos
Retired Chairman and Chief Executive Officer
Merck & Co., Inc.

And

Member, Committee on Prospering in the Global Economy of the 21st Century
Committee on Science, Engineering, and Public Policy
Division on Policy and Global Affairs
The National Academies

before the

Committee on Science
U.S. House of Representatives

October 20, 2005

Mr. Chairman and members of the Committee.

Thank you for this opportunity to appear before you on behalf of the National Academies' Committee on

Prospering in the Global Economy of the 21st Century. As you know, our effort was sponsored by the National Academy of Sciences, National Academy of Engineering and Institute of Medicine (collectively known as the National Academies). The National Academies were chartered by Congress in 1863 to advise the government on matters of science and technology.

Mr. Augustine, chair of the committee, has discussed the overall concerns the committee has about the future vitality of the United States economy. During my testimony, I will focus on the problems that we're having in K through 12 education. The committee believes the education issue is the most critical challenge the United States is facing if our children and grandchildren are to inherit ever-greater opportunities for high-quality, high-paying jobs—and our solution and recommendations to respond to the nation's challenge in K—12 science, mathematics, engineering, and technology education were the committee's top priority.

The committee found that the American public is not satisfied with the K through 12 education available for their children. They are worried about the international comparative surveys that show that children outside the United States—even those in countries with far less resources than ours—rank higher than their own children in their understanding of mathematics or science.

The committee then made the recommendation we call "10,000 teachers, 10 million minds" which proposes increasing America's talent pool by vastly improving K—12 science and mathematics education.

In developing its action steps to reach this goal, the committee first focused on what part of K—12 science, mathematics, engineering, and technology education was of greatest concern. The committee immediately recognized that many of these teachers do not have sufficient education in these fields, and its recommendations respond to that concern.

Of all its action steps, the committee's highest priority is a program that would annually recruit 10,000 of America's brightest students to the science, mathematics, and technology K–12 teaching profession. The program would recruit and train excellent teachers by providing scholarships to students obtaining bachelor's degrees in the physical or life sciences, engineering, or mathematics to gain concurrent certification as K–12 science and mathematics teachers. Over their careers, each of these teachers would educate 1,000 students, so that each annual cadre of teachers educated in this program would impact 10 million minds.

The program would provide merit-based scholarships of up to $20,000 a year for 4 years for qualified educational expenses, including tuition and fees, and would require a commitment to 5 years of service in public K–12 schools. A $10,000 annual bonus would go to program graduates working in underserved schools in inner cities and rural areas.

To provide the highest-quality education for undergraduates who want to become K–12 science and mathematics teachers, it would be important to award matching grants, perhaps $1 million a year for up to 5 years, to as many as 100 universities and colleges to encourage them to establish integrated 4-year undergraduate programs leading to bachelor's degrees in science, engineering, or mathematics *with concurrent teacher certification.*

This program, modeled after a very successful program in Texas (and which is being replicated in California), takes advantage of those people who are already in science, mathematics, engineering, and technology higher education programs and offer them the ability to get into teaching. It also incorporates in-classroom teaching experiences, master K-12 teachers, and ongoing mentoring—the combination of which produces highly qualified teachers with the skills and support to remain effective in the classroom.

Our second action step focuses on strengthening the skills of 250,000 current K–12 science and mathematics teachers through summer institutes, Master's programs, and Advanced Placement and International Baccalaureate (AP and IB) professional development programs. Each of these activities also builds on very successful model programs that can be scaled up to the national level.

In the case of the summer institutes, the committee recommends that the federal government provide matching grants for state-wide and regional 1- to 2-week summer institutes to upgrade the content knowledge and pedagogy skills of as many as 50,000 practicing teachers each summer. The material covered would allow teachers to keep current with recent developments in science, mathematics, and technology and allow for the exchange of best teaching practices. The Merck Institute for Science Education is a model for this recommendation.

For the science and mathematics master's programs, the committee recommends that the federal government provide grants to universities to develop and offer 50,000 current middle-school and high-school science, mathematics, and technology teachers (with or without undergraduate science, mathematics, or engineering degrees) 2-year, part-time master's degree programs that focus on rigorous science and mathematics content and pedagogy. The model for this recommendation is the University of Pennsylvania Science Teachers Institute.

In the case of AP, IB, and pre-AP or pre-IB training, the committee recommends that the federal government support the training of an additional 70,000 AP or IB and 80,000 pre-AP or pre-IB instructors to teach advanced courses in mathematics and science. Assuming satisfactory performance, teachers may receive incentive payments of up to $2000 per year, as well as $100 for each student who passes an AP or IB exam in mathematics or science. There are two models for this program: the Advanced Placement Incentive Program and Laying the Foundation, a pre-AP program.

The committee also proposes that high-quality teaching be fostered with world-class curricula, standards, and assessments of student learning. Here, the committee recommends that the Department of Education convene a national panel to collect, evaluate, and develop rigorous K–12 materials that would be available free of charge as a *voluntary* national curriculum. The model for this recommendation is the Project Lead the Way pre-engineering courseware.

Why are we doing this? Because, as Mr. Augustine mentions, many of the teachers who are teaching subjects have no background in the subjects that they are teaching. It is very hard for someone who does not have a physics education to turn students on to physics, because they have no basic feeling for the subject. Teachers with strong content knowledge, either through a bachelors or Masters program, who also have strong pedagogy skills and access to ongoing skills updates can be truly effective at encouraging students in science, mathematics, and technology fields. That is the thesis that we've built on.

The committee also proposes a program that will enlarge the pipeline by encouraging more students to take AP and IB science and mathematics courses and tests through providing more opportunities and incentives for middle-school and high-school students to pursue advanced work in science and mathematics. The committee suggests a national goal of increasing the number of students in AP and IB mathematics and science courses from 1.2 million to 4.5 million, and setting a goal of tripling the number who pass those tests, to 700,000, by 2010. Student incentives for success would include 50% examination fee rebates and $100 mini-scholarships for each passing score on an AP or IB mathematics and science examination.

The reason we are encouraging more students to participate in AP/IB courses is because we have found, through the Dallas-based AP Incentive Program, that those students who take AP/IB courses are twice as likely to enter and complete college as those who do not. Of particular interest is the ability of programs such as the University of California College Prep Program to reach currently underserved areas or populations of students with specific learning needs through online access to teachers and tutors.

We also propose scholarships for American undergraduates who are willing to go into science and technology and engineering and fellowship programs for those pursing graduate science and engineering degrees in areas of national need.

In sum, the committee is proposing a whole spectrum of recommendations that will enhance the quality of science, mathematics, engineering, and technology education for all American students and providing incentives for Americans to pursue higher education degrees in these fields. By taking the proposed actions, we believe that the United States will be better positioned to compete as a country for future high knowledge jobs.

Thank you for providing me with this opportunity to testify before the committee. I would be pleased to answer any questions you have about the report.

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P. ROY VAGELOS, M.D.

Retired Chairman of the Board & Chief Executive Officer

Merck & Co., Inc. – Whitehouse Station, New Jersey 08889-0100, U.S.A

Dr. Vagelos served as Chief Executive Officer of Merck & Co. Inc., for nine years from July 1985 to June 1994. He was first elected to the Board of Directors in 1984 and served as its Chairman from April 1986 to November 1994.

Dr. Vagelos joined the worldwide health products firm in 1975 as Senior Vice President of Research and became president of its research division in 1976; in addition, starting in January 1982, he served as Senior Vice President of Merck with responsibility for strategic planning. He continued to hold both positions until 1984, when he was elected Executive Vice President.

Before assuming broader responsibilities of business leadership, Dr. Vagelos had won scientific recognition as an authority on lipids and enzymes and as a research manager. This followed a decision early in his career to put his principal energies into research rather than the practice of medicine.

Dr. Vagelos received a A.B. degree (1950) from the University of Pennsylvania, where he was elected to Phi Beta Kappa, the academic honor society. He received his M.D. from Columbia University (1954) and was elected to Alpha Omega Alpha, the medical honor society. After internship and residency (1954-56) at Massachusetts General Hospital in Boston, he joined the National Institutes of Health in Bethesda, Maryland.

At the NIH (1956-66) he served in the National Heart Institute, holding positions in cellular physiology and biochemistry—first as Senior Surgeon and then as Head of Section of Comparative Biochemistry, both in the Laboratory of Biochemistry.

In 1966, Dr. Vagelos joined Washington University in St. Louis, Missouri, as Chairman of the Department of Biological Chemistry of the School of Medicine. In addition, from 1973 to 1975, he assumed more extensive responsibilities as Director of the University's Division of Biology and Biochemical Sciences, which he founded.

Dr. Vagelos has received honorary Doctor of Science degrees from Washington University (1980) for his research achievements and important influence on national science policy; Brown University (1982) for distinguished contributions to the advancement of knowledge as a teacher, research scientist, and head of one of the nation's outstanding laboratories; the University of Medicine and Dentistry of New Jersey (1984) for outstanding leadership in biomedical research leading to drugs and other therapeutic agents of direct benefits to mankind; New York University (1989) for contributions in helping to discover and produce medicines that both extend and enhance life; Columbia University (1990) for an extraordinary range of accomplishments in biological science, pharmaceutical research, and leadership in the pharmaceutical industry; the New Jersey Institute of Technology (1992) for his contributions to medical research; Pamukkale University in Turkey (1992); and the University of New York at Stony Brook (1994) for outstanding achievement; Mount Sinai Medical School (1997); and the University of British Columbia (1998). He received Honorary Doctor of Laws degrees for leadership in the battle to conquer diseases from Princeton University (1990), the University of Pennsylvania (1999) and Harvard University (2003). Rutgers University (1991) granted him honorary Doctor of Humane Letters degree in recognition of his "ambitious agenda to develop effective cures for the most perplexing illness of our time."

The author of more than 100 scientific papers, he received the Enzyme Chemistry Award of the American Chemical Society in 1967. He was elected in 1972 to the American Academy of Arts and Sciences and the National Academy of Sciences, and in 1993 to the American Philosophical Society. In 1989 he received the Thomas Alva Edison Sciences Award from Governor Thomas Kean. In 1993, he received the Lawrence A. Wien Prize in Social Responsibility from Columbia University. In 1994 he received the C. Walter Nichols Award from New York University's Stern School of Business. In 1995 he received the National Academy of Science Award for Chemistry in Service to Society. In 1998 he was awarded the Prince Mahidol Award conferred by His Majesty the King in Bangkok (Thailand). In 1999 he received the Othmer Gold Medal from the Chemical Heritage Foundation and Bower Award in Business Leadership from Franklin Institute.

Dr. Vagelos was Chairman of the Board of Trustees of the University of Pennsylvania from October 1994 to June 1999, having served as a trustee since 1988. He also served as Co-Chairman of the New Jersey Performing Arts Center from 1989-99, was President and CEO of the American School of Classical Studies at Athens from 1999-2001 and served in the National Research Council Committee on Science and Technology for Countering Terrorism in 2002.

He is currently Chairman of Regeneron Pharmaceuticals, Inc. and Theravance, Inc., two biotech companies. He is also Chairman of the Board of Visitors at Columbia University Medical Center where he also chairs the Capital Campaign. He serves on a number of public policy and advisory boards, including the Donald Danforth Plant Science Center and the Danforth Foundation.

Dr. Vagelos is married to the former Diana Touliatos. They live in New Jersey, and have four children and seven grandchildren.

Dr. Vagelos was born on October 8, 1929, in Westfield New Jersey.

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Remarks on *Rising Above the Gathering Storm*

Statement of

William A. Wulf, Ph.D.

President

National Academy of Engineering

The National Academies

before the

Committee on Science

U.S. House of Representatives

for

The Hearing on

Science, Technology, and Global Economic Competitiveness

20 October 2005

Good afternoon, Mr. Chairman and members of the Committee. My name is William (Bill) Wulf and, since 1996, I have been on leave from the University of Virginia to serve as President of the National Academy of Engineering (NAE).

Founded in 1964, the NAE provides engineering leadership in service to the nation. It operates under the same congressional act of incorporation that established the National Academy of Sciences, signed in 1863 by President Lincoln. Under this charter the NAE is directed "whenever called upon by any department or agency of the government, to investigate, examine, experiment, and report upon any subject of science or art [technology]." The NAE's 1998 strategic plan, however, goes beyond this reactive, "whenever called upon", role to one in which we are to "Promote the technological health of the nation …". It is much in the latter spirit that I am here today.

I am particularly delighted to be here in the company of Norm Augustine, former Chairman of the NAE, to testify on what I believe to be the most important (as opposed to urgent) issue facing our country. I was not a member of Norm's Committee, but I participated in its initial meeting and tracked its progress closely, so I first want to acknowledge and thank all of the stellar committee members for the enormous energy and creativity that went into producing the report. I hope that the Science Committee will appreciate that the Academies' committee's willingness to spend countless hours on this report was the result of their depth of concern over our nation's future.

I cannot hope to represent the content of "Rising Above the Gathering Storm" as well or as fully as Norm Augustine or Roy Vagelos, so I won't try – but I would like to draw attention to three points.

First, unfortunately the problem is a "creeping crisis".

Unfortunately the problems we are concerned about don't have a Sputnik-like wake-up call.

You all know the storied procedure for boiling a frog. They say that if you drop a frog in boiling water, it will jump out. But, if you put a frog in cool water and heat it very slowly, the frog won't jump out, and you'll get a boiled frog. The theory is that each small, incremental rise in temperature is not enough of a crisis to make the frog react. I don't know if this story is true, but it fits my purpose—the slowly warming water is a creeping crisis for the frog!

Our creeping crisis is not a slow, one-dimensional change like the frog's water temperature. We are facing a number of problems—each one like a tile in a mosaic. No one of these problems by itself creates the sort of crisis that provokes action. But if you stand back and look at the collection of problems, a disturbing picture emerges—a pattern of short-term thinking and a lack of long-term investment. It's a pattern for preserving the status quo rather than reaching for the next big goal. It's a pattern that presumes that we in the United States are entitled to a better quality of life than others and that all we have to do is circle our wagons to defend that entitlement. It's a pattern that does not balance the dangers and opportunities in current circumstances.

I do not have the time to discuss all the tiles in this mosaic, and I would be largely redundant with the report that is the subject of this hearing if I did, but they include:

- The dramatic decline in industry-based basic research.

- The flat-to-declining federal support of research in the physical sciences and engineering.

- The increasingly short-term, risk-averse nature of the research that is supported.

- The discouraging effect on foreign students and scholars of our current visa policies, and its impact on our ability to get the world's best and brightest to come to the U.S. and contribute to our security and prosperity.

- The draconian proposals for handling of "deemed exports" in basic research, and their chilling impact on long-term basic research at universities.

- The rapid growth in the use of the category of "sensitive but unclassified" information, and its impact on the free flow of scientific information.

Second, nonetheless the problem is both important and widely recognized.

Although the problems depicted in "Rising Above the Gathering Storm" may not have a Sputnik-like wake-up event, that does not mean they are unimportant. Quite the contrary; in my view collectively they are the most important issue currently facing the United States. I am hardly alone in that view; there is an increasingly wide recognition of it. Below are references to recent reports from a variety of sources that reflect this deep concern:

- From the National Academies [1, 2]

- From the private sector [3, 4, 5, 6, 7, 8]

- From Government agencies [9, 10, 11, 12], and

- From Academia [13, 14]

Despite the differing perspectives of the authoring organizations, there is surprising consistency among these reports. They all identify problems like the tiles in my mosaic as representing serious long-term problems for the country – problems that require action now! As is said in the American Electronics Association (AeA) report[3]:

"We are slipping. Yes, the United States still leads in nearly every way one can measure, but that does not change the fact that the foundation on which this lead was built is eroding. Our leadership in technology and innovation has benefited from an infrastructure created by 50 years of continual investment, education and research. We are no longer maintaining this infrastructure."

In my view, the erosion alluded to by the AeA, if unchecked, will lead to a poorer quality of life for our grandchildren—and quite possibly to a world that is less secure and less free.

Third and finally, it's all about innovation and the multi-faceted environment that supports innovation.

There is wide agreement in the reports cited above that the US ability to innovate has been the source of its prosperity—and hence that ensuring our ability to continue to innovate is central to our future prosperity and security. Each of these reports proposes specific policy options to do this—many of them are similar, but few are identical. I think that is because, in my view, there is no simple formula for innovation. There is, instead, a multi-component "environment" that collectively encourages, or discourages, innovation. Just to mention a few of the components of this environment:

• There must be a vibrant research base.

• There must be an educated workforce.

• There must be a culture that permits and even encourages risk-taking.

• There must be a social climate that attracts the best and brightest to practice engineering – whether from within the country or outside it.

• There must be "patient capital" available to the entrepreneur.

• The tax laws must reward investment.

• There must be adequate and appropriate protection for intellectual property.

• There must be laws and regulations that protect the public while also encouraging experimentation.

To prosper in the future we must attend to all the components of this innovation environment—and in particular we need to be sure that they are attuned to the current and future technologies rather than those of the past (when many of the components of the environment were first created).

In summary

By almost any objective measure, the U.S. is doing very well at this moment. But, the prosperity and security that we now enjoy is the result of decades of investment, research and education. We now see a pattern, a "mosaic", of disinvestment, of a retreat from bold research, and of a declining interest of American youth in education in science and engineering. We see a pattern suggesting a shift from creating the new to protecting the status quo. No single tile in this mosaic is going to ruin the American economy – which perhaps makes it all the more dangerous. There is the chance that we won't take action until the consequences become apparent in a decade or two, at which point it will be too late.

Thank you for the opportunity to testify, Mr. Chairman. I would be pleased to answer any questions the Committee might have.

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Descriptive Biography of Dr. William A. Wulf

Dr. Wulf was elected President of the National Academy of Engineering (NAE) in April 1997; he had previously served as Interim President beginning in July 1996. Together with the National Academy of Sciences, the NAE operates under a congressional charter and presidential executive orders that call on it to provide advice to the government on issues of science and engineering.

Dr. Wulf is on leave from the University of Virginia, where he is a University Professor and the AT&T Professor of Engineering and Applied Science. Among his activities at the University were a complete revision of the undergraduate Computer Science curriculum, research on computer architecture and computer security, and an effort to assist humanities scholars exploit information technology.

In 1988-90 Dr. Wulf was on leave from the University to be Assistant Director of the National Science Foundation (NSF) where he headed the Directorate for Computer and Information Science and Engineering (CISE). CISE is responsible for computer science and engineering research as well as for operating the National Supercomputer Centers and NSFNET. While at NSF, Dr. Wulf was deeply involved in the development of the High Performance Computing and Communication Initiative and in the formative discussions of the National Information Infrastructure.

Prior to joining Virginia, Dr. Wulf founded Tartan Laboratories and served as its Chairman and Chief Executive Officer. Before returning to academe, Dr. Wulf grew the company to about a hundred employees. Tartan developed and marketed optimizing compilers, notably for Ada. Tartan was sold to Texas Instruments in 1995.

The technical basis for Tartan was research by Dr. Wulf while he was a Professor of Computer Science at Carnegie-Mellon University, where he was Acting Head of the Department from 1978-1979. At Carnegie-Mellon Dr. Wulf's research spanned programming systems and computer architecture; specific research activities included: the design and implementation of a systems-implementation language (Bliss), architectural design of the DEC PDP-11, the design and construction of a 16 processor multiprocessor and its operating system, a new approach to computer security, and development of a technology for the construction of high quality optimizing compilers. Dr. Wulf also actively participated in the development of Ada, the common DoD programming language for embedded computer applications.

While at Carnegie-Mellon and Tartan, Dr. Wulf was active in the "high tech" community in Pittsburgh. He helped found the Pittsburgh High Technology Council and served as Vice President and Director from its creation. He also helped found the CEO Network, the CEO Venture Fund, and served as an advisor to the Western Pennsylvania Advanced Technology Center. In 1983 he was awarded the Enterprise "Man of the Year" Award for these and other activities.

Dr. Wulf is a member of the National Academy of Engineering, a Fellow of the American Academy of Arts and Sciences, a Corresponding Member of the Academia Espanola De Ingeniera, a Member of the Academy Bibliotheca Alexandrina (Library of Alexandria), and a Foreign Member of the Russian Academy of Sciences. He is also a Fellow of five professional societies: the ACM, the IEEE, the AAAS, IEC, and AWIS. He is the author of over 100 papers and technical reports, has written three books, holds two US Patents, and has supervised over 25 Ph.D.'s in Computer Science.