Is America Falling Off the Flat Earth?

Norman R. Augustine, Chair, Rising Above the Gathering Storm Committee, National Academy of Sciences, National Academy of Engineering, and Institute of Medicine of the National Academies

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***Rising Above the Gathering Storm* Committee**

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PREFACE

Our institutions—the National Academy of Sciences, the National Academy of Engineering, and the Institute of Medicine—are deeply concerned about the nation's ability to compete during the 21st century. Prompted by a bipartisan request from Congress, we undertook a study that culminated in the report *Rising Above the Gathering Storm: Energizing and Employing America for a Brighter Economic Future*, released in late 2005.

We were subsequently encouraged as President George W. Bush introduced his American Competitiveness Initiative and as both the Senate and House passed bills based on ideas from the report and from others. At least one newspaper in every state of the Union had an editorial page item indicating the need for action on this issue. We held a major meeting with more than 1,000 participants from all 50 states—both in person and virtually—to discuss ideas for actions that could be initiated at the regional, state, and local levels. Yet, we still have a long way to go for our nation to be competitive in future decades, when our children and grandchildren will need jobs and desire a standard of living at least as good as today's.

This essay, by Norman Augustine, the chair of the committee that developed the *Rising Above the Gathering Storm* report, provides a timely update on the proposals raised in the report. As he has in speeches throughout the country, Norman Augustine continues to make the case that action is needed so that the United States remains competitive in the 21st century. Although the responsibility for the content of this essay rests with the author, we fully support the goals that he expresses in it.

In 2006, the National Academy of Sciences presented Mr. Augustine with its most prestigious award, the Public Welfare Medal, to honor his contributions to the vitality of

science in the United States by bringing to industry and government a better understanding of the crucial role that fundamental scientific research must play in our long-term security and economic prosperity. Our entire nation—and its scientific and engineering enterprises in particular—owes an enormous debt to Norman Augustine. Acting on his strong personal conviction that sound national policy must embrace the very best in science and engineering, he has made a great difference in our nation's life and welfare.

Ralph J. Cicerone
President
National Academy of Sciences

Charles M. Vest
President
National Academy of Engineering

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CONTENTS

EXECUTIVE SUMMARY

The aviation and telecommunication revolutions have conspired to make distance increasingly irrelevant. An important consequence of this is that US citizens, accustomed to competing with their neighbors for jobs, now must compete with candidates from all around the world. These candidates are numerous, highly motivated, increasingly well educated, and willing to work for a fraction of the compensation traditionally expected by US workers.

If the United States is to offset the latter disadvantage and provide its citizens with the opportunity for high-quality jobs, it will require the nation to excel at innovation—that is, to be first to market new products and services based on new knowledge and the ability to apply that knowledge. This capacity to discover, create and market will continue to be heavily dependent on the nation's prowess in science and technology.

Indicators of trends in these fields are, at best, highly disconcerting. While many factors warrant urgent attention, the two most critical are these: (1) America must repair its failing K-12 educational system, particularly in mathematics and science, in part by providing more teachers qualified to teach those subjects, and (2) the federal government must markedly increase its investment in basic research, that is, in the creation of new knowledge.

Only by providing leading-edge human capital and knowledge capital can America continue to maintain a high standard of living—including providing national security—for its citizens.

IS AMERICA FALLING OFF THE FLAT EARTH?

In October 2005, the National Academies, in response to a bipartisan request by members of the US Senate and House of Representatives, issued a report titled Rising Above the Gathering Storm: Energizing and Employing America for a Brighter Economic Future *stating that America is in substantial danger of losing its economic leadership position and suffering a concomitant decline in the standard of living of its citizens because of a looming inability to compete in the global marketplace. Since that time, well over 100 editorials and op-eds have appeared in the nation's newspapers, at least one in every state, addressing this issue. Virtually all supported the Academies' conclusions.*

The president of the United States incorporated a number of the Academies' recommendations in his 2006 State of the Union Address, and various bills were introduced in the Senate and House, almost all on a bipartisan basis, to implement many of the recommendations. The continuing resolution that established the federal budget in several relevant fields for FY 2007 provided an important step forward in preparing America for the intensifying global competition for jobs. Similarly, the House of Representatives (by votes of 389-22 and 397-20 on key bills) and the Senate (by a vote of 88-8) took steps to authorize many of the Academies' recommendations in the FY 2008 budget. Final approval in the House of the America COMPETES Authorization Act was passed by a unanimous consent vote following a 367-57 approval of the conference report. President Bush signed the legislation on August 9, 2007. Private firms are also stepping forward: the ExxonMobil Foundation recently committed $125 million to help implement one element of the Academies' proposals: improving America's K-12 education system in science and

mathematics. But competitiveness is a long-term challenge and much remains to be done in the months ahead.

Meanwhile, our competitors have not been standing still. The World Economic Forum dropped America from first to seventh place in its ranking of nations' preparedness to benefit from advances in information technology; the number of US citizens entering engineering school declined still further; the remnants of the legendary Bell Labs, the birthplace of the laser and the transistor and the home of many Nobel laureates, were sold to a French firm; a new generation of semiconductor integrated circuits—the mortar of the modern electronics revolution—was introduced; the largest initial public offering in history was conducted by a Chinese bank; another $650 billion has been spent on US public schools while the performance of its students on standardized science tests of those about to graduate declined further; American companies once again spent three times more on litigation than on research; and in July, for the first time in history, foreign automakers sold more cars in the United States than American manufacturers.

The competitiveness issue as seen some 18 months after the National Academies' study was completed is the topic of this essay. Its content is based on congressional testimony and a series of lectures by the author and thus offers a less formal but updated version of the findings in the Academies' report. Although this essay draws heavily on that report and other sources, the views expressed herein are those of the author.

CAN AMERICA COMPETE?

The answer to that fundamental question seems, at least on the surface, less than straightforward. On one hand, America's overall competitiveness as assessed by the World Economic Forum in Geneva recently plummeted from first place to sixth place in a single year. Perhaps even more perplexing, the news media have reported that a city in Pennsylvania not long ago considered adopting the slogan "Pittsburgh can become the Bangalore of America." And few passengers on the main railroad line connecting New York City and the nation's capital, can observe the large sign that for nearly 100 years has adorned the bridge crossing the Delaware River near Trenton, New Jersey, and reads "Trenton Makes, the World Takes" without having to suppress a mixture of nostalgia and bemusement. On the other hand, America this past year accomplished an extraordinary sweep of science-related Nobel prizes; the overall economy continues to be reasonably sound; and an extraordinary Team USA took first place at the 2007 International Biology Olympiad, squeezing past Team China. The US team's Gold Medal winners were Meng Xiao He, Barry Liu, Mark Shteyn, and Helen Yang.

The answer to the competitiveness question is much clearer when one considers, as Wall Street insiders like to say, "broad forward-looking indicators." Most of the indicators convey a troubling message, one that strongly suggests that America is rapidly losing its competitive position to steadily progressing economies, primarily in the developing world—a world populated by substantial numbers of highly motivated, increasingly well-educated, low-paid workers.

Over the years, global leadership has come to be accepted by many US citizens as an American province—which it often seemingly has been, particularly in the closely related fields of science, engineering, and innovation. But leadership is *not* an American

birthright. In this regard, it is useful to recall that Spain was a leading power in the 16th century; France dominated the 17th century; and England the 19th. It is also useful to remind ourselves, as economics historian Angus Maddison points out, that as late as 1870 China's economy was nearly twice the size of the US economy. Seemingly, the only thing that stays the same in the worlds of politics and economics is the persistence of change.

The book on the 21st century is, of course, yet to be written, but if history teaches any lesson it is that *no* nation has an inherent right to greatness. Greatness has to be earned and continually re-earned. In fact, few nations, great or ordinary, have survived to enjoy the third century of their existence. Nations that take their technologic leadership for granted will be particularly vulnerable in this fast-moving global community in which there are said to be more scientists at work than existed throughout all prior eras combined.

Typifying our misconception of an assured position at the forefront of science and engineering is a revealing story told by Dan Goldin when he was administrator of the National Aeronautics and Space Administration (NASA). It seems that he was being excoriated by a critic of NASA who objected particularly to the government's spending on weather satellites. The skeptic asked, "Why do we need meteorologic satellites when we have the Weather Channel?"

In the same vein, former Air Force Chief Scientist and Princeton engineering professor Cort Perkins tells of sailing into Woods Hole Harbor, where he was greeted by a friend whose boat was moored in the adjacent slip. The neighbor's fiberglass vessel was adorned with nylon lines, Dacron sails, a high-strength aluminum alloy mast capped with a radar antenna, and a bridge replete with the latest versions of GPS, depth finders, and radio equipment. Its owner, an attorney, was carrying a 10-megapixel digital camera with a stabilized lens and wearing photosensitive sunglasses. His clothing was made of synthetic fibers, and his shoes sported nonslip neoprene soles. In his pocket was a Blackberry. He cheerily greeted Professor Perkins, asking, "So have you technologists done anything for us lately?"

There have, of course, been ample indicators that the canary in the US competitiveness mine is not well. They include the National Commission on Excellence in Education's 1983 report *A Nation at Risk*, which urged more demanding high-school graduation requirements, measurable standards throughout K-12, and higher qualifications for teachers. The 1985 report of the President's Commission on Industrial Competitiveness (also known as The Young Commission, after its chairman, Hewlett-Packard CEO John Young), *Global Competition: The New Reality* urged greater emphasis on science and technology and broad K-12 education reform. The Council on Competitiveness's 2004 report *Innovate*

America: Thriving in a World of Challenge and Change proposed an urgent legislative agenda to make America more competitive. The Task Force on the Future of American Innovation's 2006 report *Measuring the Moment* warned that "those who stand still will fall behind. . . . If the United States continues to stand still [specifically in basic research in the physical sciences], it faces inevitable decline." The Council of Graduate Schools 2007 report *Graduate Education: The Backbone of American Competitiveness and Innovation* asserted that "we can no longer take for granted America's continued leadership in innovation and competitiveness."

Indeed, during the past 3 years alone, at least 16 significant reports on America's growing competitiveness *dis*advantage have been issued by such reputable organizations as the Council on Competitiveness, the Business Roundtable, the Brookings Institution, the Association of American Universities, the Center for Strategic and International Studies, the National Association of Manufacturers, the President's Council of Advisors on Science and Technology, the Task Force on the Future of American Innovation, the Technology CEO Council, the US Chamber of Commerce, The Council of Graduate Schools, and the National Academies.

Today, it is possible that our nation's adult generation will, for the first time in history, leave their children and grandchildren a lower sustained standard of living than they themselves enjoyed. Should that occur, it will be the consequence of a collective failure to respond to the increasingly clear signals that are emerging, and indicate that we have entered a new era, a global era, an era in which Americans must compete in the marketplace not merely with each other but with highly qualified people around the planet. It will represent a change of seismic proportions with commensurate implications for America's economic well-being, national and homeland security, health care, and overall standard of living.

At the same time, it must be recognized that the nations currently leading the global competitiveness surge are not without their own challenges. China, for example, is still basically an agrarian society with almost half its workers engaged in farming. Its gross domestic product per capita is only 17% of that of the United States. The corresponding value for India is but 9% of America's. Thirty-five percent of India's citizens survive on a daily household income of about $1 per person; but remarkably, this portion has been reduced from 50% in 1984. As developing nations prosper their governments may seek a disproportionate share of corporate earnings in the form of taxes and thereby undermine the progress that has been made. Other developed nations probably face even greater challenges than the United States, for example, Western Europe with its high labor costs,

short workweek, and resistance to change—particularly when established social benefits are at risk. But it is of little consolation that others may be even closer to the edge, at least at this moment, than we. The words of London consultant Mark Foster ring true: "The change is from globalization going one way to globalization going every way."

The impact of this tidal wave will be felt for many years by the citizens of all nations—and not all equally. As the Council on Competitiveness warns, "Simply being an American does not guarantee a high-wage job anymore."

DISTANCE IS DEAD

An all-important trend, driven largely by advancements in science and engineering, has been gradually engulfing the globe. It has been referred to by Frances Cairncross, of *The Economist*, as "the death of distance"—a phenomenon whereby in many circumstances parties to transactions no longer need to be physically close to one another. When first considered, that may seem rather mundane, but its consequences are already permeating the lives of almost all the citizens of this planet and are profound indeed.

For example, in the past, a consumer who sought to purchase a household item would visit perhaps two or three retail establishments within convenient walking or driving distance and acquire the desired item from the provider who offered the best overall promise of satisfaction. Increasingly, however, that consumer, rather than going to the garage and starting the engine of an automobile, goes to his or her desk and starts a *search* engine on a *computer* to see what supplier *somewhere in the world* offers the best overall deal. Similarly, an employer seeking workers welcomes applications on the Internet from around the planet. Corporations deciding where to locate new factories, offices, and research laboratories search the entire globe for promising venues. And most investors exploring financial opportunities do not limit their search to local concerns.

It is indicative of this pace of change that barely 100 years earlier the above consumer would have gone neither to a desk to start a computer nor to a garage to start an automobile, but to the barn to start a horse. My mother, who was born in Colorado in 1893 and lived to be 105 years old, knew people who had crossed the prairie in a covered wagon, and she had met astronauts who had walked on the moon. Project that change forward a century, substantially accelerate it, and one can only begin to imagine the magnitude of change that will have to be absorbed in the years ahead. Former Secretary of Education

Richard Riley estimates that the top 10 jobs of a handful of years from now don't even exist today—a possibility that makes preparation particularly challenging and places a premium on the contributions of creative people with broad experience motivated to exploit opportunities.

Microsoft Chairman Bill Gates observed that "the Internet will be to the 21st century what aviation was to the 20th century." Indeed, the airline terminal does have a new companion: the computer terminal. In the most recent century, it became practicable to move objects, including people, around the world at near the speed of sound and at moderate cost with previously unimagined safety. It is now feasible to move *information* in a similar fashion, but literally at the speed of light and almost without cost. Reflecting that, Americans now average 14 hours a week on line. The processing, storage, and transmission of information will soon become "virtually" free, thereby changing the entire paradigm for the handling of knowledge. In short, there is indeed no longer a "there" there. There is *here*. And it is here *now*.

The extent of the telecommunication revolution is suggested by the 35 *trillion* e-mails that are currently sent each year; or the growth of Wikipedia, in its 249 languages, from 100 million words at the beginning of 2004 to about 2 billion words less than 3 years later; or the increase in cell-phone users from 2 per 1,000 people in 1990 to over 400 today; or the increase in Internet users from about 2 million to over 1 billion in a little over 15 years.

Many examples of the death of distance are already to be found in our daily lives:

- If a consumer places a telephone call to a service department to resolve a problem with a computer, bank account, golf reservation, or lost airline bag, there is a nontrivial likelihood that the consumer will speak with a person in Bangalore, Jamaica, or some other such place. One international call center is now being operated by the prisoners in Rome's Rebibbia Prison. In India, courses are offered to teach students to speak with a midwestern accent to prepare them better for jobs in call centers.

- In Washington, DC, visitors to an office building not far from the White House are greeted by a pleasant woman whose image appears on a flat-screen display in the lobby where she handles appointments, access, and other administrative matters. But she is not in Washington, DC—she is in Pakistan. At some time in the foreseeable future, when the impact of ever-advancing 3-D television research

becomes "reality," there will be little apparent difference between being greeted by a virtual receptionist on another continent and by a real receptionist a few feet away.

- Much of the commercial software now prevalent in the United States is constructed in India, where at the end of each day teams of workers transmit the results of their efforts to American integrators and testers who are just beginning *their* day, and the product of their efforts is transmitted back to India in time for the start of the next day's work, thereby doubling the pace and cutting the cost with which software can be produced.

- Many Americans' income tax returns prepared by major accounting firms are processed in India.

- US architectural firms are having drawings produced in Argentina.

- J.P. Morgan conducts a significant part of its derivatives operations in Mumbai.

- Nearly one in 20 Americans now works for a foreign-owned company.

- The CAT scans of patients in a number of US hospitals are routinely read by radiologists in Australia or Bangalore.

- When I spoke via teleconference with groups from Harvey Mudd College and Harvard University about the impact of an emerging China on global competitiveness, the first question asked of me came from—where else?—China, from a student listening in the middle of the night via webcast.

- Recently suffering a GPS failure while seeking to locate a package-delivery firm's warehouse in the Washington, DC, area, I called the firm's "800" number on a cell phone and was given real-time driving instructions by the help service: "Turn right at the traffic light by the Exxon station," and so on. The speaker was in India.

- Americans are increasingly obtaining their health care overseas, where (according to *The Washington Post*) dentists, for example, "charge one-fifth to one-fourth of US prices."

- In 2001, a patient in Strasbourg, France, had his gallbladder removed by a surgeon in New York who was using a remotely controlled robot. (As an engineer, I hope there was a backup surgeon in the room!)

Indeed, candidates for many jobs traditionally in the United States are now just a mouse click away.

During my youth in Colorado, the locals used to take considerable pleasure in pointing out to visiting Texans that Colorado was actually bigger than Texas if you just flattened it out! Tom Friedman, writing in his extraordinarily insightful book *The World is Flat*, takes this notion to an entirely new level: not only *is* the world flat, but many heretofore relatively unknown parts are very significant indeed. He observes that globalization has "accidentally made Beijing, Bangalore, and Bethesda next door neighbors."

Foremost among the consequences of the death of distance is that a large number of jobs, with the exception of those demanding proximity between the parties involved, will be opened to the global job market. And far fewer jobs are "safe" than many might imagine. Indeed, most Americans paid little attention to the job losses that initially were confined largely to assembly workers, but the phenomenon of "offshoring" soon migrated to writing software, back-office administrative work, and, more recently, professional pursuits. It has been said that a recession is when your neighbor is out of work, but a depression is when *you* are out of work. To many Americans who thought their jobs were safe, the competitiveness trend looks more and more like a depression.

Alan Blinder, the former vice chairman of the Federal Reserve Board, succinctly observed that janitors, taxi drivers, and crane operators are "*probably*" immune to foreign competition. It seems in retrospect that even that view was a bit optimistic, at least as far as taxi drivers and janitors are concerned. Early models of autonomous vehicles are already being tested on closed roadways, and a small robot vacuums the floor of my home—and does a remarkably good job, too. It figures out how large the room is and therefore how long to work, locates any concentration of dirt for extra attention, cleans under beds, and even knows not to fall down the stairs. When it needs energy, it plugs itself into its charging station. It always shows up for work and does not require the filling out of reams of Social Security, tax, immigration, liability, unemployment-compensation, and medical-coverage forms. It was, of course, made in China—no doubt by other robots, probably also made in China. In this spirit of internationalism, a portable DVD player that I recently purchased in suburban *Washington, DC*, was emblazoned with the words, "Hecho en China."

Dr. Blinder estimates that about 50 million of our jobs (almost one-third of the total) are potentially capable of being exported. Others consider that estimate to be low. Indeed, as Clyde Prestowitz has pointed out, 3 billion new capitalists entered the global job market since the fall of traditional Communism and the events that followed. That alone is, at least in theoretical terms, about 20 candidates for every existing job in America. A number

of those candidates are not now qualified for the positions held by many Americans, but that too is changing. The magnitude of the revolution is suggested by the fact that 150 nations seek to participate in the global economy, compared with 87 just 25 years ago.

The question arises, "Will we all end up working at McDonald's?" The answer is no, because those jobs aren't safe either. McDonald's, it seems, has been experimenting with a centralized order-taking system wherein drive-through customers speak their meal requests into a voice recorder that transmits them via a synchronous equatorial satellite orbiting some 23,000 miles above Earth to a central facility staffed by people who are *expert* in taking orders. The requests are then re-entered digitally and transmitted via satellite to the person who prepares hamburgers and fries—a communication trip equivalent to four transits around the earth. Using this process, McDonald's has cut its error rate in half and increased its throughput by 30%. As it happens, the central ordering facility is, at present, in Colorado Springs, but it could just as easily be in Alice Springs, in the Outback of Australia.

Initially, many of the jobs threatened by the global employment revolution moved to Mexico, but those jobs are now moving out of Mexico, which by the new global standard is becoming high-priced albeit not nearly as high priced as the United States. Vietnam, India, Malaysia, Brazil, Indonesia, and China were among the immediate beneficiaries of the new wage disparity. However, as reported by Tom Friedman, firms in *India* are now beginning to outsource work to Uruguay.

Few Americans have been to Guandong, Zuzhou, Mumbai, or Bangalore, but if they went they would probably receive a rude awakening in the form of large numbers of highly motivated, well-trained workers, often surrounded by state-of-the art equipment. One who harbors any doubts about the latter need only visit Biopolis in Singapore, CERN in Switzerland, or the nuclear-fusion research facilities in China. In fact, five of the top 10 exporters of high-technology products are emerging economies, compared with just 2 two decades ago.

Fareed Zakaria, the editor of Newsweek, has noted that "of Wal-Mart's 6,000 suppliers, 5,000—80%—are in one country . . . and it isn't the United States." The economic impact on both nations is evident: the city of Beijing alone is adding 30,000 cars each month. China already has more than twice as many mobile-phone users as the United States. A few years ago, the mayor of Shanghai told me that over one-third of the construction cranes in the world were in his city. Between now and 2015, half the construction on Earth is planned to take place in China. About 22 billion square feet of buildings, mostly commercial, are being added each year; the total existing US commercial infrastructure

amounts to about 60 billion square feet. Research centers are being built in China that rival entire US cities in size. China's national bird is now said to be the construction crane.

What does all that mean to an American hoping to hang on to his or her job? What is clear is that attempting to build "walls," in the form of economic barriers, around the United States will simply ensure that we are left in isolation and become increasingly irrelevant as the rest of the world moves rapidly forward. Ironically, China itself tried this in the 15th century and again in the 20th . . . with the predictable result both times. The Red Queen, speaking to Alice in Lewis Carroll's *Through the Looking Glass*, offers better advice: "*Here*, you see, it takes all the running *you* can do, to keep in the same place. If you want to get somewhere else, you must run at least twice as fast as that!"

THE GATHERING STORM

A study was conducted by the National Academies in 2005 that has important implications for all Americans. Titled *Rising Above the Gathering Storm: Energizing and Employing America for a Brighter Economic Future,* the study was requested, on a bipartisan basis, by Senators Lamar Alexander and Jeff Bingaman, of the Senate Committee on Energy and Natural Resources, later joined by Representatives Sherwood Boehlert and Bart Gordon, of the House Committee on Science and Technology. Its purpose was to examine an issue that was becoming an increasing concern to many Americans: the outlook for our nation's prosperity. The effort turned out to be particularly timely—or perhaps a bit late. For example, in a recent PriceWaterhouseCoopers poll, 48% of the executives surveyed said they believed that the United States has lost competitive ground in recent years, whereas only 9% believed that the country had moved ahead in this regard.

By way of background, the National Academies is an independent, nonpartisan, not-for-profit, invitational professional organization consisting of three components. The first, the National Academy of Sciences, was created by President Lincoln and chartered by Congress in 1863 with the express purpose of providing advice on public-policy issues involving science. It was later joined by the National Academy of Engineering and the Institute of Medicine, each with a corresponding mission in its own fields of expertise. The Academies currently count 195 Nobel laureates among their membership. Participants in its studies serve pro bono.

The National Academies' 2005 study of competitiveness involved 20 people and was allotted 90 days for its conduct. The book containing the investigation's results was 564 pages long and provided a series of findings with supporting data, four overarching recommendations, and 20 highly specific implementing actions.

Members of the Academies' competitiveness study group included the CEOs or former CEOs of several corporations, including ExxonMobil, DuPont, Intel, Merck, and Lockheed Martin; the presidents or former presidents of several universities, including Yale, Rensselaer, the University of Maryland, Texas A&M, and the Massachusetts Institute of Technology (MIT); three Nobel laureates; a state superintendent of schools; and several former presidential appointees, one of whom has since become secretary of defense.

The committee's first action was to gather almost 70 subject-matter experts in Washington, DC, for a weekend of discussions. Apropos of the topic, much of the group's work was conducted via cyberspace. The committee's final report was anonymously critiqued by 37 reviewers selected by the Academies before its release and ultimately came to be known as the *Gathering Storm* report—after the first line in its title, *Rising Above the Gathering Storm: Energizing and Employing America for a Brighter Economic Future*.

The thrust of the Academies' findings is straightforward. First, the report concludes that individual prosperity depends predominantly on individuals having high-quality jobs. It also observes that the same is true of a nation's collective prosperity, in that if there are few high-quality jobs, there are not likely to be sufficient tax revenues to ensure homeland security, provide health care, pay Social Security, or educate the nation's children. Second, the report concludes that the creation of new, high-quality jobs is today disproportionately dependent on advances in science and engineering.

Eight studies conducted in recent decades indicate that public investments in science and technology have produced annualized societal returns that range from 20% to 67%. Some economists estimate that about half the nation's growth in gross domestic product per capita during the last half-century can be attributed to scientific and engineering achievements. An assessment conducted by the Bank of Boston a decade ago concluded that research performed at MIT alone had resulted in the creation of 1.1 million jobs in 4,000 new companies. Alan Greenspan, then Federal Reserve chairman, cited innovation as the reason for significant gains in productivity growth since 1995 and told Congress: "Had the innovations of recent decades, especially in information technologies, not come to fruition, productivity growth would have continued to languish at the rate of the preceding twenty years." In recent decades, 60-80% of all newly created jobs have been in small to medium-sized companies (with fewer than 500 employees).

Given the increasing pace of advancement in science and technology—and their close companion, innovation—it seems highly likely that these disciplines will have equal or greater impact in the decades ahead. Some 5 million researchers around the world are now at work in the pursuit of new knowledge. According to the Federal Reserve Bank of

Dallas, each year enough new information (of all types) goes into storage somewhere in the world to equal 37,000 Libraries of Congress. Former President Bill Clinton observed that "where once nations measured their strength by the size of their armies and arsenals, in the world of the future knowledge will matter most."

The leaders of other nations are unlikely to overlook the ubiquitous impact of investment in science and technology. For example, of China's top nine leaders, eight are engineers, the other a geologist. In contrast, in the United States, the number of members of the most recent 435-member House of Representatives who listed their field as "engineering" was three, the same number who categorized themselves as "actors or artists." As for scientists, none was to be found in the Senate, but representation in the House recently ballooned to five.

At last year's multiday meeting of China's National Academies of Science and Engineering, China's President Hu, the prime minister, and all the members of the Politburo were present for most of the meeting. It has been observed that President Hu, who in his address to the gathering referred to China as "an innovation-driven nation,"could have taken most of the actions he proposed directly from the US National Academies' report. Some years earlier, Deng Xiaoping abruptly dismissed any ideologic debate that might be prompted by China's commitment to scientific and engineering competition in a free market, noting that "it doesn't matter if it's a black cat or a white cat. As long as it can catch mice, it's a *good* cat!"

Indeed, in 2006, China announced a *15-year* plan—that it termed "*medium- to long-term*"—for the further development of science and technology. The plan calls for increasing the contribution of science and technology to equal 60% of the country's overall economic growth by the end of the period. Contrast that approach with that of America's government, which generally considers "long-term" to mean 5 years, or America's industry, which too often considers "long-term" to mean anything beyond the next quarter.

But it is not simply America's economy that depends on the nation's prowess in science and engineering. In fact, many of the demanding challenges facing the country today will require advances in science and engineering, including challenges in providing health care, supplying energy, protecting the environment, ensuring homeland security, finding and providing water, and maintaining a vibrant economy. Paul Peercy, chair of the Engineering Deans Council of the American Society for Engineering Education, observed, "I used to say 'Look around, everything except the plants is engineered.' Now I say, 'Look around, everything *and* some of the plants are engineered.'"

"AMERICA, WE HAVE A PROBLEM"

How are we doing in the global competition for jobs? The unanimous answer of the members of the Academies' Gathering Storm committee is, not well.

For example

- The US share of the world's *leading-edge* semiconductor manufacturing capacity dropped from 36% to 11% in the past 7 years.
- Chemical companies closed 70 facilities in the United States in 2004 and were in the process of closing 40 more the following year. Of the 120 new plants costing over $1 billion each that were under construction at that time, 50 were in China and one was in the United States.
- The US Big Three automakers announced the closing of 26 plants in the United States over the next several years, while Japan-based companies are opening four new plants in the United States between 2006 and 2008.
- There are now 12 energy companies in the world whose reserves exceed those of the largest US energy firm, ExxonMobil.
- IBM recently sold its once-promising PC business to a Chinese company.
- In *Business Week's* ranking of the world's information-technology companies, only one of the top 10 is based in the United States.

- In spite of America's growing demand for energy, no new petroleum refineries have been built and no new nuclear power plants have been ordered in the past 30 years. (France now derives 78% of its electric power from nuclear sources; Lithuania, 72%; Belgium, 54%; Armenia, 42%; Japan, 30%; and the United States, 19%.)

- Nearly 60% of the patents filed with the US Patent and Trademark Office in the field of information technology now originate in Asia.

- Once-mighty Ford and General Motors both have junk-bond ratings, and each has laid off over one-third of its dwindling North American workforce in the past 5 years alone.

- Last year Toyota brought to an end the notion of the US Big Three automakers when it sold more vehicles *in the United States* than Chrysler.

- This year, rapidly expanding Toyota ended General Motors's 75-year reign as the world's largest auto manufacturer.

- Only one of the 25 largest initial public offerings last year took place on American exchanges.

- China is on track to build 108 new airports between 2005 and 2010, including the world's largest. The United States, in spite of stifling congestion, has built only one major airport in the last third of a century.

- Low-wage firms, such as Wal-Mart and McDonald's, created 44% of the new jobs in America during one recent period—a period during which high-wage firms produced only 29% of the new jobs.

- Americans are now "saving" a net *negative* 0.4% of their disposable income.

- In 2000, the number of foreign students studying physical sciences and engineering in *US* graduate schools surpassed, for the first time, the number of US students.

- The *Los Angeles Times* reports that in the past 16 years two high-rise buildings were constructed in Los Angeles as the city executed its accelerated urban-renewal plan. In the past 10 years, 5,000 were built in Shanghai.

- Some foreign universities are now conducting their engineering and business classes in English to promote recruitment of faculty and students and simplify access to technical information. In contrast, the working language in the back halls of many US engineering schools is Chinese.

- The United States is falling relative to its economic competitors in broadband Internet access. As recently as 2000 it was in first place; now it ranks 16th in the fraction of citizens having broadband connections and 61st in the use of mobile telephony per capita. South Korea has nearly *twice* the broadband penetration (subscribers per capita) of the United States.

- Toyota now has over 5 times the market capitalization of General Motors and Ford *combined*.

- The United States ranks 17th among nations in high-school graduation rate and 14th in college graduation rate.

- Foreigners finance about two-thirds of US domestic investment, compared with about one-fifteenth a decade ago.

- China has supplanted the United States as the world's number 1 *high-technology* exporter.

- During the past 30 years, 40% of new petroleum production came from industrialized nations. It is estimated that during the next 40 years, 90% will come from developing nations.

- Well over half the world's foreign-exchange resources are held by emerging market countries: the poorer nations are now financing the richer nations.

- The German firm that a decade ago purchased one of America's Big Three automobile makers, Chrysler, for $36 billion decided after 9 years that it didn't want the company after all and in effect paid nearly $700 million to get someone else to take it away (*along with its pension liability*).

- Of the new R&D sites planned for construction in the next 3 years by the 177 companies queried in one recent survey, 77% are to be built in China or India, often using US corporate financing.

An analysis conducted by Marie and Jerry Thursby for the National Academies Government-University-Industry Research Roundtable titled *Here or There: A Survey of Factors in Multinational R&D Location* records the findings of a survey of US and European firms that recently established, or plan to establish, R&D sites in an emerging economy. The top 10 reasons for choosing a selected location were the country's growth potential, followed by the availability of highly qualified personnel, the existence of local customers, the strength of intellectual-property protection, the ease of negotiating intellectual-property rights, the inherent cost of conducting R&D, the ease of collaborating with local universities, the availability of university faculty with scientific or engineering expertise, the absence of regulatory and other restrictions, and the suitability of the country as an export platform.

The bottom line is that the United States is today a net importer of *high-technology* products. It took slightly less than a decade for the US trade balance in high-technology manufactured goods to shift from a positive $40 billion in 1990 to a negative $50 billion in 2001. In fact, Americans now pay almost as much to foreign firms for imports as they pay to their own government in taxes. In a recent article, *Business Week* asks, "Why is that important?" and then answers its own question: "Because for the past 70 years Washington has been the 800-pound gorilla, more powerful by far than any other force in the US economy. That's not true any more." As *USA Today* (speaking of foreign financial reserves) puts it, "Developing nations have gone from beggar to banker." Indeed, in just 7 years the United States has tripled its foreign debt. And although a great deal of attention has been focused on China and India because of their size and potential, *The Economist* reminds us that "these two together made up less than one-quarter of the total increase in emerging economies' gross domestic product last year [2005]." Such is the magnitude of the competitiveness challenge that is sweeping the globe in this chaotic new-world disorder.

But is it not good that other nations prosper? In the view of the National Academies' competitiveness committee, the answer is a resounding "Absolutely." In a world in which half the population lives on less than $2 per day, a prosperous world will almost certainly be a safer world, not to mention a more humane world. Similarly, a prosperous world will provide more potential customers for US products and cheaper and more diverse products for US consumers. Prosperity is not necessarily a zero-sum game, but there will inevitably be winners and losers. The National Academies' Gathering Storm committee, in its work on competitiveness, sought to ensure that America would remain among the *winners*.

Early projections as to the outcome of this global contest, which bears such enormous stakes, are already beginning to arrive. For example, I recently traveled some 7,000 miles on the Trans-Siberian Railroad and had the opportunity to visit—with the help of interpreters—with a broad spectrum of citizens of those remote regions. Russians, perhaps understandably pragmatic, are projecting the outcome of the world competitiveness race in the form of a joke that one repeatedly hears on the streets: "The *optimists* are studying English, the *realists* are studying Chinese, and the *pessimists* are buying Kalashnikovs."

THE DINOSAURS NEVER SAW IT COMING

The enigma, of course, is that America, by most measures, is prospering today. The nation produces 28% of the world's economic product with less than 5% of the world's population. America's economy has been creating nearly 2 million *net* new jobs a year. *Business Week* ranks 8 US firms in the top 10 "most innovative" companies in the world. America has a gross domestic product close to $13 *trillion* and has contributed one-third of the growth in global output over the most recent 15-year period. Its household net worth is now over $55 *trillion*. U.S. universities employ 70% of the world's Nobel Laureates.

According to the *Times* of London, seven of the top 10 universities in the world are in the United States. Jiao Tong University in China says the number is 8 of 10. It is interesting that a dissenting opinion comes from the US National Conference of State Legislatures in its recent report *Transforming Higher Education*, which concludes that although America has many fine colleges and universities, excellence is by no means uniform. It goes on to state flatly that "the American higher education system is no longer the best in the world. Other countries outrank and outperform us." America's academic institutions nonetheless have a culture that encourages innovative thinking and the free exchange of ideas, and our society, even with its shortcomings, is virtually unparalleled in its ability to absorb motivated, contributing people from around the world. Perhaps most important, we enjoy the benefits of a stable government and an economic system that encourages risk-taking and, left to itself, vigorously filters out noncompetitive firms and industries in favor of the growth firms and industries of tomorrow. Protectionism in the United States, although clearly not dead, seems to be *in extremis*.

All that comes at a price. To produce such great accomplishments, our economic system, evidencing its version of what has been called creative destructionism, *destroys* 29 million jobs each year while generating 31 million *new* jobs. In fact, about one-sixth of all jobs in the United States are destroyed in any given year. Mathematicians would describe the process as encompassing the most hazardous of calculations in that it concerns relatively small differences between relatively large numbers, and economists would say that the job market is highly volatile. But if one assumed a 10% adverse change in both job creation and job destruction, it would result in the *disappearance* of twice as many net jobs as are now being *added*. Such is the tenuousness of life in a modern economy.

If the overall economy is doing so well, what is the concern?

In a word, *trends*.

Not only are others getting better, but also to a disconcerting degree America has in many respects been losing its own edge. Truly, America has enjoyed what for many have been the best of times—seldom if ever has the world seen a single nation with such broad predominance—but these are also the worst of times, inasmuch as we are slipping perilously and silently closer to the flat earth's edge. Ironically, the nations that are emerging as our most serious competitors are doing so in large part by adopting the best of our institutional practices and often executing them better than we. In America, we are to a considerable degree living off past investments, the comparatively strong position the nation held at the end of World War II, and the prevalence of English as the predominant language of business, government, and technical education. But the impact of those discriminators appears to be diminishing. Simply stated, we have been eating our seed corn.

Worse yet, this is a crisis that provides no sudden, dramatic warning as did, say, 9/11, Sputnik, and Pearl Harbor. In the present instance, the analogy much more closely matches the proverbial frog being slowly boiled. We are witnessing a gradual, albeit accelerating, erosion rather than a single cataclysmic wakeup call.

Charles Darwin observed that "it is not the strongest of the species that survives, nor the most intelligent, but the one most responsive to change." That conclusion seems to apply to human organizations as well as to biological organisms. There can be no more dangerous place to be than in first place: the one holding that exalted position becomes everyone else's target and, perhaps worse, is the recognized beneficiary of the status quo—and therefore reluctant to promote, or even accept, change.

We, of course, did not get into our intensifying plight overnight. Correspondingly, if we should fall decisively behind the leaders of the rest of the world, particularly in the prosperity drivers of science and engineering, it will take decades to catch up, if it is possible to do so at all. Consider the matter of producing one additional research scientist who can help to generate the knowledge from which future innovation and jobs will spring. Rather convincing empirical evidence suggests that most children who are "turned off" by mathematics and science have already arrived at that conclusion by the time they are in fourth grade. The die is usually cast by a teacher who finds teaching science and mathematics an unwelcome and intimidating burden or by a parent with a disinterest in or disdain for these fields.

One of the unusual characteristics of a technical education is that by eighth grade a student must most often decide whether to *preserve the option* to pursue such a career, for example, in science or engineering, by deciding whether or not to take algebra to be prepared for higher-level science and mathematics courses in high school. That is in distinct contrast with the decisions faced by those who might wish to *preserve the option* to become lawyers, bankers, accountants, or medical doctors. The reason for the disparity is the hierarchic nature of an education in mathematics that serves as the foundation of science and engineering. One cannot usefully study trigonometry until one has mastered algebra (only 13 states currently require algebra II for a high-school diploma . . . up from 2 states in 2005); one cannot study calculus until one has learned something of trigonometry; and one cannot study differential equations until one has studied calculus. So fundamental is mathematics that it is in essence the language of science and engineering.

Assuming that a person has completed the requisite courses during 4 years in high school and has successfully completed 4 years of undergraduate work (the average for engineers is now closer to 6 years), the person is prepared to begin a 6- or 7-year pursuit of a PhD, after which a creative research career can presumably begin. A few more years may in many cases be devoted to postdoctoral endeavors.

As one might suspect, there is a great deal of leakage along that extended educational highway. To begin with, about one-third of US eighth-graders do not receive a high-school diploma. And of those who do, about 40% do not go on to college. About half who do begin college do not receive a bachelor's degree. Of those who do receive such a degree, two-thirds will not be in science or engineering. And of those who are US citizens and *do* receive degrees in either science or engineering, only about 1 in 10 will become candidates for a doctoral degree in those fields. And over half the doctoral candidates drop out before being awarded a PhD.

Furthermore, even after they receive their degree, a growing proportion of US graduates—in the case of baccalaureate engineers, slightly over half—decide to become investment bankers on Wall Street, lawyers, corporate executives, or some other form of worker. More S&P 500 CEOs receive their undergraduate training in engineering than in any other field, in spite of the minority of undergraduates who receive degrees in that field. About 23% of the nation's CEOs majored in engineering, 13% in economics, and 12% in business; the remainder are trained in a broad variety of other disciplines. It can justifiably be argued that those who migrate from science or engineering into other fields still use their education for the betterment of society, but they generally do not then directly contribute to the nation's research enterprise. The point is that it takes a lot of third-graders to produce one contributing research scientist or engineer and a very long time to do it.

But that is only the beginning. The newly minted scientist or engineer must continue to pursue his or her education and the search for knowledge, at least informally, at an ever-increasing pace throughout his or her career or become professionally "middle-aged" by the time they are 30 years old. That is a consequence of the exploding supply of technical information in the world, which is said to double about every 2 years. Studies of the frequency of citations of scientific and technical articles suggest a half-life of such information, depending on the field, of about 3 to 6 years. Similarly, studies of the course content in university catalogs and qualitative surveys of science and engineering professionals indicate that, absent continued learning, the professional value of the specific knowledge imparted through their formal studies becomes negligible in about 5 years. This perhaps explains why there are seemingly always engineers seeking employment at the same time that employers are decrying an "engineering shortage." Employers are seeking integrated-circuit and jet-engine designers, not vacuum-tube and propeller designers.

WELCOME TO THE 21ST CENTURY BOARD ROOM

Imagine, for a moment, that one is sitting in a board meeting of a Fortune 100 company with several billion dollars to devote to the establishment of a major new facility somewhere in the world. The board is reviewing management's proposal as to where the facility—and the jobs it generates—should be located. In the past 2 decades, I have participated in over 500 board meetings of Fortune 100 firms and not infrequently wrestled with that very question.

Several books and numerous articles have decried the lack of "loyalty" of America's CEOs and boards of directors to the American worker when making such decisions. Before attempting to address that accusation, it is instructive to ask, What *is* an American firm? For example, one respected company with which I have been associated as a director for 18 years was founded in the United States well over 170 years ago and maintains its headquarters in the United States, but some 10% of its owners (shareholders) are foreign; over half its customers are foreign; over half its employees are foreign; and not long ago its CEO was foreign. Is that an *American* firm, or is that a *global* enterprise? And even if it were judged "an American firm," the most disastrous thing a CEO could do for any firm's employees and shareholders alike would be to make business decisions designed to protect the interests of a few if those decisions are harmful to the competitiveness of the organization as a whole and thus endanger the prosperity, even survivability, of the enterprise itself—and the jobs and profits it sustains.

Turning from the topic of corporate nationality to the related subject of the heritage of specific products, Boeing's new 787 has major assemblies manufactured in Europe, Asia, and North America and components from countries virtually thoughout the world.

A recent *USA Today* article pointed out that 59% of the parts content of the "*US*" General Motors Chevrolet HHR is *not* made in the United States or Canada (revealingly, the US government's reporting system does not distinguish between the two countries) and, furthermore, is assembled in Mexico. In contrast, 85% of the parts content of the "*Japanese*" Toyota Sienna is made *in* the United States or Canada, and it is assembled in Indiana. The question is, Which is the *American* car? General Motors spokesperson Greg Martin helps to answer that question: "We're a global car company," he explains, "that happens to be based in the United States." The world's borders are becoming increasingly indistinct. Several years ago when traveling in Peru and visiting with the owner of a small kiosk, I asked whether the gentleman had ever been to the United States. "No," he replied, "only to Miami!"

In the case of most large US employers, it is quite probable that a substantial majority of their shares are owned by institutional investors, and the primary, if not sole, interest of that set of shareholders is financial return—preferably *near-term* financial return—and certainly not the matter of preserving jobs. In fact, announcements of job layoffs in times of prosperity are almost always greeted favorably on Wall Street. Ironically, the institutional investors who own those companies often are fiduciaries for the pension funds of American *workers*—workers who, for their own part, have seldom displayed any great reluctance to purchase foreign-made cars, television sets, and DVD players if they thought doing so was in their immediate interest as consumers. Perhaps one should not be surprised by this proclivity, at least when it comes to cars: US-based *Consumer Reports* identifies only one traditional US brand in its top dozen automobiles as ranked by reliability.

Few would disagree with the observation that most large US firms are becoming global enterprises. A more recent and less noticed trend is that many US universities are following suit. It is well known that universities often have one or two foreign affiliations, but this practice is now expanding to the point where some institutions have numerous locations abroad. Thus, universities are also gradually losing their national identity. Not atypically, the University of Chicago states, "We educate the next generation of the world's leaders, not just United States leadership," and a few years ago, 260-year-old Princeton University changed its motto from "In the Nation's Service" to "In the Nation's Service and in the Service of All Nations."

THE COMPETITIVENESS EQUATION— THE COST OF LABOR

Among the first factors considered by a corporate board in determining where to locate a new facility often is the cost of labor. If that is not the case, the implication is that the firm has found a way to operate its business with little labor content, that is, without creating many jobs. If the company is concerned with hiring factory workers, it will undoubtedly be noted that nine such workers can be hired in Mexico for the cost of one in the United States. I recently visited a plant in Vietnam where 20 assembly workers could be hired for the cost of 1 in the United States. As far as labor wrap-rates are concerned, the US worker would have to take a 95% cut in pay and benefits simply to be on an even footing with a counterpart in Vietnam from the standpoint of cost. Needless to say, few US workers would do so willingly.

In recognition of these trends, a new "international standard" of comparative wages has emerged in recent years: the "McWage." The McWage is what McDonald's pays its beginning employees in various countries, and it reveals an average pay differential of a *factor* of 12 between the US worker and workers in low-wage countries. Not 12%. Not even 120%. A factor of 12—1,100%.

But perhaps it is not factory workers who are needed for the new facility being considered; perhaps it is engineers and scientists. In this case, eight engineers can be hired in India for the cost of one in the United States. Five chemists can be employed in China for the cost of one in the United States. And they may well be graduates of the renowned

Indian Institute of Technology, Tsinghua University of China, or one of America's foremost universities. Some studies indicate still greater exchange ratios for engineers and scientists in Russia; however, the data on Russia are notoriously imprecise, as well as volatile.

Such disparities will presumably narrow when other economies and their citizens prosper, as indeed is already beginning to happen. But global wage equivalence appears to be a long time away—much longer than America can afford to wait before addressing its competitiveness shortcomings. There is also, as critics point out, the possibility of major political upheavals in developing countries that could have significant effects on the competitiveness of those nations—but it seems unwise to predicate America's future on such destabilizing events. It thus appears highly likely that the United States will suffer a substantial wage disadvantage for many years to come and that some means will have to be found to offset that fundamental tilt of the flat earth away from America.

THE COMPETITIVENESS EQUATION— THE QUALITY OF THE WORKFORCE

Economist Lester Thurow wrote nearly 2 decades ago that "in the 21st century, the educational skills of the workforce will end up being the dominant competitive weapon." If so, it appears that America is becoming a formidable threat—to itself.

A workforce that costs more than its competitors can, within reason, overcome this disadvantage through productivity, although the increase in productivity in some instances can itself destroy jobs. Indeed, major steps have been taken in improving efficiency in the United States, with, for example, real factory output per worker having increased from $52,000 to $108,000 since 1990 alone. That is important, but it falls far short of the wage gap that must somehow be offset—particularly as others have improved their productivity, too.

The most obvious place to begin when assessing workforce quality in a knowledge age is with educational qualifications. In China, virtually all high school students study calculus; the corresponding share in the United States is 13%. In 1970, US students made up 30% of all university enrollments in the world; by 2000, the fraction had dropped to 12%. Similarly, the share of PhDs (in all fields) granted by US universities will have declined from 50% in the early 1970s to a projected 15% in 2010. Fewer than 18% of US high-school graduates go on to receive a college degree within 6 years of receiving

their high-school diplomas. The United States still leads in the fraction of the population's 35- to 64-year-olds who hold college degrees (in any field), but it ranks seventh among 25- to 34-year-olds. For every American elementary and secondary school student studying Chinese, there are 10,000 students in China studying English. China already is the largest "English-speaking" nation on the globe, although English is a *second* language. When I visited China in the late 1970s, English lessons were being given over the loudspeakers in the street cars. How long do you suppose US commuters would tolerate mandatory Chinese lessons on their way home from the office?

The situation in science and technology is particularly perilous. In the Program for International Student Assessment tests of students' ability to apply mathematical understanding to real-world problems, US 15-year-olds finished in 24th place among the participating nations. US 15-year-olds finished in 18th place in science. In a test of basic knowledge of both mathematics and science, US 12th-graders finished below the students of 18 other countries in math, and 15 in science. In yet another test, American 8th-graders ranked 9th in science and 15th in mathematics, behind Estonia and Malaysia. The earlier (1999) Trends in International Mathematics and Science Study found *no* country with 12th-graders scoring significantly below those in the United States in mathematics and only one in physics. Of US students who take the ACT college-entrance examination, a self-selecting and presumably more highly achieving group, 78% are deemed *un*qualified for college-level work in reading, mathematics, or science.

In a 2005 test of science understanding administered by the National Assessment of Educational Progress, 32% of US fourth-grade students performed below the "basic" achievement cutoff level (the lowest of three levels defined for the test). Among 8th-graders, the share increased to 41%. By the 12th grade, the fraction of underachievers had grown to 46%. In mathematics, the same test revealed that fewer than one-fourth of high-school seniors perform at or above their grade level.

An examination of the trend over time is no more encouraging. In the abovementioned test of mathematics understanding, the proportion of American high-school seniors scoring below the "basic" cutoff level in 1996 was 31%; in 2000, it was 35%; and by 2005, it had grown to 39%. Recent changes in the test's methods reduce the confidence one can attach to the trend analysis, but it seems clear that the average level of mathematical understanding attributable to high-school seniors is low and not improving, and these results exclude the 1 million students who are generally not among the top performers and drop out of high school each year.

Ironically, US 4th-graders rank near the 80th percentile among nations participating in 2003 science testing, but by the 12th grade, US students plummet to the 5th percentile. Similarly, by the 12th grade, US students descend to the 10th percentile in mathematics (in 1995, the most recent year for which data are available). A benchmark test given to US students in 2005 indicates that over the most recent decade, 4th-graders modestly improved in mathematics and science, 8th-graders remained basically unchanged in performance, and 12th-graders lost additional ground. In fact, other tests displayed that 17-year-olds have not improved in scores in mathematics for a quarter-century. It seems that the longer our children are exposed to our K-12 education system, the worse they do.

If we wish to be *average* by global standards, we will need to *improve* a great deal. Can anyone imagine a football coach at any American high school greeting his players on the first day of fall practice by saying, "This year let's get out there and try to be average for the Gipper!"?

It can, of course, be argued that comparing averages and medians tells only part of the story, as indeed is often the case. But in this instance, further parsing of the data generally reveals that the United States has a disproportionately small share of the highest performers and a disproportionately large share of the lowest performers. Although this is widely overlooked, it is not simply the poorer-performing students who are falling through the gaping cracks of our educational system but also the highest performers who—much to the nation's detriment—are frequently being forced to learn in an environment approaching the lowest common denominator.

As former Federal Reserve Chairman Alan Greenspan explains, "If you don't solve [the K-12 education problem], nothing else is going to matter all that much." In choosing words to characterize the present health of the US public K-12 education system, he selected "pretty awful." Speaking from the perspective of business, the president of the US Chamber of Commerce, Thomas Donohue, says, "If companies were run like many education systems, they wouldn't last a week."

As one digs deeper, additional societal concerns emerge as consequences of the nation's education shortcomings. For example, according to the Federal Reserve's data, during the 15 years ending in 2004, the net worth of families led by college graduates increased by 61% while that of families led by high-school dropouts rose by only 12%; the disparity generated *during the above period* eventually exceeded a factor of 6. In 1980, college graduates, on the average, earned 75% more than high-school graduates (and 150% more than those without a high-school diploma). In today's knowledge age, a quarter-century later, the wage gap between high-school and college graduates is over

130%. Households led by a college graduate have, on the average, more than 4 times the net worth of households led by high-school graduates with no college education. Over the past 2 decades, median *real* income has declined (by about 10%) for all households except those including a recipient of a bachelor's or higher degree—the latter having seen an increase. Greenspan notes that "it's pulling our society apart." His successor as chairman of the Federal Reserve, Ben Bernanke, adds that "we're probably not doing what we should be doing in terms of ensuring that all children have opportunities to learn mathematics and science."

Finding a solution to America's failing K-12 performance is complicated by the character of the nation's education delivery system that comprises some 15,000 school districts that are locally managed, generally apply local budgetary policies with local hiring and retention practices, and often use local standards of achievement. Certainly not all schools are failing, but the *average* of all schools is certainly failing, and failing resoundingly. Bill Gates has remarked, "When I compare our high schools to what I see when I'm traveling abroad, I'm terrified for our workforce of tomorrow." I had a similar reaction when, as but one example, I visited a school in Sri Lanka in an area that not long before had been ravaged by the tsunami of 2004. There, amidst the wreckage of homes and in the heat and humidity of a tropical jungle, attentive children were attending school in open-air classrooms. Encouragement was taken by some observers in 2005, when 65,000 US students participated in Intel's global science and engineering fairs. But it should not go unnoticed—even with recognition that quality is far from uniform—that 6 *million* students took part in the corresponding events in China. Yet the Asia Society reports that China educates 20% of the world's students with only 2% of the world's educational resources.

Jay Greene points out that inflation-adjusted spending per public school student in the United States increased by a factor of 7 from the end of World War II to the present, but 12th-grade test scores have remained substantially unchanged over that extended period, as has the high-school graduation rate. The United States spends more per student on secondary education than any other nations except Switzerland and Luxemburg and more on primary education than any nation except Luxemburg. The problem appears to be not *what* we are spending but rather *how* we are spending it. States, on the average, spend only 61% of their education budget on classroom instruction. The nation's capital, which ranks third in spending per pupil, finds itself in last place in the fraction of its budget dedicated to instruction—53%. As the nation awaits fundamental structural changes, most of which must be introduced at the local level, more funds will need to be devoted, at least in the near term, at the national level—hopefully to jump-start a turnaround. In the judgment of many, America's K-12 educational process simply needs to embrace the

free-enterprise system—with its competition, measurable standards, and consequences for all—and make performance-related compensation the coin of the realm, as is the case in virtually every other pursuit in the nation and, increasingly, in the world.

A few years ago, it was reported that California was taking action in that regard: In 1999, it passed a law mandating that students pass an exit examination to receive a high-school diploma. A passing grade in mathematics was set at 55%. The examination was multiple-choice, with four possible answers to each question; seemingly, this at least assured the not-unlucky, totally uninformed student of a 25% score, for openers. Furthermore, students were permitted as many as six tries to pass the examination in the normal course of affairs and even more in "special" circumstances. Yet there emerged a cacophony of objections by vocal citizens who believed even this set of undernourished standards to be too demanding, and a series of lawsuits and political maneuverings arose to eliminate the requirement. Similarly, attempts by a few school boards around the country to lengthen the school year by a week or two have not infrequently resulted in decisive action: the members of the school board were summarily thrown out of office by enraged parents.

The problem of low expectations has not been confined to California. Alabama, for example, reported that in 2005, 83% of its fourth-graders ranked as "proficient" on its *state* test of academic achievement. But in the most widely accepted *national* test, the National Assessment of Educational Progress, only 22% of Alabama's fourth-graders scored at or above the proficient level. In truth, *neither* of the measures matters much. What counts today is how the children of Alabama rank with the children of Singapore, Moscow, Hong Kong, Delhi, Beijing, and Berlin. There is little consolation in being first among losers.

A Gallup poll offering 20 options reported that the American public ranks lack of student motivation, lack of parental involvement, and home-life issues as the three factors adversely affecting the nation's public schools. In sharp contrast, participants in the Teach for America program, which seeks highly qualified new college graduates to teach in challenged public schools, rank teacher shortcomings, principal shortcomings, and inadequate expectations of students as predominant.

The foremost conclusion of the National Academies' Gathering Storm committee was that along with increasing parental interest and involvement in our public schools and their children's education, the greatest leverage for improving K-12 performance resides in providing qualified, motivated teachers, particularly in mathematics and science. In generations past, America's classrooms were the beneficiary of an abundance of extraordinarily capable women who, because of the failings of those eras, had only the most

limited set of career opportunities other than teaching. Today, many of these would-be teachers are not in the classroom at all but instead are in the executive suite, operating room, or law office. The impact on the nation's schools is palpable.

According to the most recently available data, 69% of US fifth- through eighth-grade students are being taught mathematics by teachers who *do not* possess a degree or certificate in mathematics. Fully 93% of students in those grades are being taught physical sciences by teachers with no degree or certificate in the physical sciences. Even in high school, the corresponding likelihoods are 31% for mathematics, 61% for chemistry, and 67% for physics. (In contrast, 81% of the physical-education teachers in grades 5-8 and 9-12 have degrees in physical education.) Many entire school districts do not have a single teacher with an academic degree in mathematics or science.

If it offers any consolation, help is on the way: English-speaking tutors, many with master's degrees in mathematics or science, are now available over the Internet from South Africa, India, and Israel; they generally charge $3-20 per hour. One wonders whether this might be a precursor of outsourcing the teaching of our children.

Often, physical-education teachers are simply assigned to teach physics; anointed might be a more descriptive term. Many of them have a distinct lack of interest in the subject they must teach and a lack of comfort with it that is both evident and contagious to their students. The dearth of background and excitement on the part of these teachers translates into a lack of intriguing experiments that can be conducted in a science class, a lack of real-world applications that can be presented in a mathematics class, and a lack of interesting and provocative insights that can be offered in both. Thus, when a Raytheon survey asked 11- to 13-year-olds whether they would rather clean their room, eat their vegetables, go to the dentist, take out the garbage, or learn mathematics and science, fully 84% simply went with the garbage. Tom Friedman asks, "If Einstein were alive today and learned science the boring way it is taught in many US schools, wouldn't he have ended up at a Wall Street hedge fund rather than developing theories of relativity for a Nobel prize?"

The inadequacies of the nation's public school systems spill into our colleges and universities in a domino-like effect: three-fourths of all 2- and 4-year institutions feel compelled to offer remedial courses. Twenty-two percent of all freshmen enroll in mathematics remediation.

In most school districts, physical-education teachers are paid on the same wage scale as physics teachers, and excellent physics teachers are paid the same wages as mediocre

physics teachers, on the grounds that this is "fair." But when we encounter a pursuit that *really matters* in our secondary-education system, we somehow manage to find a solution to the pay conundrum: for example, we put a priority on paying our high-school football coaches very well for the extra duties they perform. Not surprisingly, a *Sports Illustrated* online survey reveals that the nation's university students believe overwhelmingly that the athletic departments in their institutions have more power than the academic faculties. The public K-12 school system in the United States continues to be largely impervious to the forces of the free-enterprise system.

About 46% of new teachers abandon the profession within 5 years. The attrition rate is even higher among science and mathematics teachers. In 2004, in Maryland, my home state, 523 mathematics teachers resigned. In spite of a monumental effort, only 91 qualified replacements could be hired. The situation is even worse in the case of physics teachers. Geoffrey Summers, of the University of Maryland Baltimore Campus, noted that "if we add four physics teachers per year in Maryland public schools we will double the rate of physics teachers that Maryland currently produces." That is in a state with nearly 6 million inhabitants. Maryland is not alone in this respect. Before the University of Texas initiated its UTeach program, of which more will be said, only 16 of 12,000 graduates in 1996 were certified to teach secondary science and 5 to teach mathematics. At the University of North Carolina, Erskine Bowles, in his inaugural address as president, remarked, "Think about this: in the past 4 years, our 15 schools of education at the University of North Carolina turned out a grand total of three physics teachers. Three. And we're going to compete with those guys in Asia? Come on—not that way." And a recent article in *Science* points out that "last year, BYU, a private institution run by the Mormon Church, graduated roughly five percent of all the new physics teachers produced by all U.S. colleges and universities in 2006. Its class of 16 dwarfs the production of any other university."

Why do classroom teachers abandon the profession? There are, of course, a plethora of reasons: lack of prestige, lack of inherent discipline in the classroom, lack of parental support, demanding work, inadequate pay, and so on. The number 1 source of dissatisfaction among teachers in low-poverty suburban public schools is, according to one survey, poor salary (51% of respondents), but among high-poverty public schools, the lack of administrative support (50%) ranks number 1. *U.S. News & World Report* states that whereas a high-school teacher must work 43 hours to make $1,000, the average corporate CEO can do so in 2 hours and 55 minutes. Kobe Bryant takes only 5 minutes and 30 seconds on the basketball court—and Howard Stern need labor only 24 seconds in *his* chosen profession.

Simply stated, if a teacher is to inspire today's young people, that teacher had better be

excited about the subject at hand, be knowledgeable enough to answer penetrating questions, and be informed enough to provide interesting, challenging coursework. The evidence along those lines is not encouraging. For example, the *Los Angeles Times* reported that last year 35% of the future elementary-school instructors who studied at California State University, Northridge, said to be the largest supplier of new teachers to the Los Angeles Unified School District, received Ds or Fs in their first college-level mathematics class. And with today's inflated grading standards at most colleges and universities, it is not easy to get a D or an F.

Some have suggested opening the K-12 teaching ranks to practicing engineers and scientists who wish to change careers or take early retirement to meet new challenges or who are simply committed to the cause. Ironically, examples are rife wherein such people are denied the opportunity to teach 9th-grade algebra but are permitted to teach in a research university. In my own case, I would be deemed unqualified to teach in virtually any grade school in America, but was welcomed, on taking early retirement from a position in the aerospace industry, to teach both undergraduate and graduate students in the School of Engineering and Applied Science of Princeton University.

The US Department of Education estimates that 60% of the new jobs that will open in the 21st century will require skills possessed by only 20% of the current workforce. Similarly, industry surveys indicate that 90% of the fastest growing jobs will require at least some post-secondary education. Jobs that demand technical training are growing at 5 times the rate of those requiring non-technical skills. And, as has been widely publicized, a person with a bachelor's degree will have median lifetime earnings that exceed earnings of those with only a high-school diploma by about $1 million.

Most parents don't seem to be losing much sleep over all this. One survey found that 70% of the parents of America's high-school students believe that their children get about the right amount of science and mathematics. A Harris poll reports that 58% of Americans believe that the United States is performing "very well" or "somewhat well" in mathematics and science education compared with other nations. And in another poll, only 15% of the parents surveyed indicated that the most pressing problem facing high schools in their communities was "low academic standards." In contrast, 73% cited "social problems and kids that misbehave."

Nor do students themselves seem to be losing much sleep over an issue that will have such a profound impact on their lives. About 83% of students eligible for *free* tutoring elect to forgo it. The average American youth now spends 66% more time watching television than in school (a number that is beginning to diminish as students devote more

time to increasingly realistic but generally educationally hollow video games). Over 40% of America's 4- to 6-year-olds have their own television sets in their bedrooms. In the case of their older brothers and sisters, the fraction approaches 70%.

When MIT made the materials it uses in its courses available free of charge on the Internet, well over half the users were outside the United States. Roy Singham, CEO of ThoughtWorks, which has operations around the world, observes, "When you're in college drinking beer and watching the Super Bowl, your counterpart in China is on his fourth book."

Could it be that most of America's parents and students "just don't get it"? That question, as far as students are concerned, was actually addressed in the Trends in International Mathematics and Science Study 1998/99. When it comes to self-perception, American youth truly excel. In fact, it was no contest. US high-school seniors ranked number 1 among the 20 participating nations in agreeing that they were doing well in mathematics and number 3 in agreeing that they were doing well in science. The problem is that the same group of students finished 18th in the mathematics examination and 17th in the science examination. As my young son once announced on the opening day of yet another soccer season, "This year we're really gonna' get 'em; last year we were too overconfident!" Indeed, it seems that at least when it comes to science and mathematics, America's youth rank considerably higher in confidence than in competence.

Tom Friedman, writing in *The Earth Is Flat*, takes a somewhat more critical perspective. "Mathematics and science," he says, "are the keys to innovation and power in today's world." He goes on to say that "American parents had better understand that the people who are eating their kids' lunch in mathematics are not resting on their laurels." He describes a conversation with his own daughters that began, "Girls, when I was growing up, my parents used to say to me, 'Tom, finish your dinner. People in China and India are starving!' My advice to you is: 'Girls, finish your homework. People in China and India are starving . . . for your jobs.'"

There is yet another critical ingredient of workforce quality: motivation—the drive to apply one's talents. This is seldom mentioned in most competitiveness debates; generalizations tend to be unfair to that not insignificant segment of the workforce that *is* highly motivated and possessed of a strong work ethic. But, as IBM's Nicholas Donofrio, puts it, "The attitude I see in Estonia, Mexico, Brazil, China, Latvia—they're hungrier than we are." Employers in many of those countries take the "default" position vividly expressed by former Green Bay Packers coach Vince Lombardi: "If you are not fired with enthusiasm, you will be fired with enthusiasm." My own experiences in visiting over 100 countries

suggest that it is difficult to name five in which, on average, customers receive worse service than in the United States.

Gilman Louie, the Silicon Valley entrepreneur and former CEO of the high-technology firm In-Q-Tel, tells of attending a lecture by an industrial leader in Japan at which the student audience spontaneously began chanting in unison the Japanese word for innovation. Some businesses in India outfit work cubicles with cots for employees who elect to work late and remain overnight. On a visit to Bangalore, I was told that the young engineers and computer scientists writing software were so committed to their tasks that if an employer simply provides them pizza (yes, in India!) for dinner, "the kids will work all night." In contrast, in a recent survey of 431 US business leaders, nearly three-fourths cited a lack of work ethic and professionalism as a characteristic of US high-school graduates. (As a case in point, I recently had difficulty gaining the attention of a clerk at—where else?—the customer-service desk of a local computer store because of her ongoing telephone conversation with a boyfriend. When the clerk finally appeared in front of me, I, rather amused by the ridiculousness of the situation, smilingly remarked, "You know, if you worked for me, I'd fire you!" The clerk returned my smile and replied, "That's why I don't work for you!"

USA Today reports one US business executive as saying that "[organizations] are realizing it's less risky to [employ] internationals because they're more coachable, more socialized, have no posses, and have not been Americanized." That executive predicts that in his field, by about 2010, foreigners will fill 50% of all the jobs available, compared with the roughly 25% they fill today. The article goes on to assert that US youth are "lacking the fundamentals."

The executive being quoted was not whom one might expect. It was not the CEO of some high-technology company, such as IBM, Microsoft, or Dell. Rather, it was George Raveling of *Nike*—speaking of basketball players in the National Basketball Association!

Raveling's remarks are echoed by Red Auerbach, legendary coach of the Boston Celtics: "All those years I traveled overseas and held clinics, I said to people, 'You know what? There's going to come a day when these countries are dangerous for us because these guys are *listening*. You look at the foreign kids who come over and everyone of them is solid fundamentally. Not our guys. No one can teach them because they all think they are stars when they're 15." As if to punctuate his observation, the United States had just finished in sixth place in the world basketball championships.

Former NBA executive Jerry Colangelo could easily have been referring to America's free-enterprise system and our system of higher education rather than basketball (or base-

ball, for that matter) when he lamented, "We invented the game, we taught people how to play the game, and they came back and knocked us off the perch." The two teams in the 2007 NBA finals, San Antonio and Cleveland, had half and one-fourth of their players from abroad (including the tournament's Most Valuable Player), respectively. Their players came from Argentina, France, Slovenia, Netherlands, Lithuania, Serbia and Montenegro, Brazil, and the Virgin Islands. No fewer than 28 countries were represented on the rosters of playoff teams. NBA Commissioner David Stern is reported in the abovementioned *USA Today* article as being "startled at how fast the rest of the world has come along." To take an example from another sport invented in the United States, fully 44% of the starting line-ups in last year's major league baseball all-star game were foreign-born. This trend is being replicated in many fields other than basketball and baseball in which, ironically, other nations are successfully adopting our own proven but oft-ignored practices. In the case of economic competitiveness, the nations posting the most remarkable gains in recent years have to a large extent been doing so simply by copying the attributes of our systems of higher education, business management (pre-Enron era), and free enterprise and in many instances implementing them more effectively than we.

David Gergen describes a presentation by Harvard economist Richard Freeman that provides a good summary of the above considerations: Freeman "argued that we have been sugar-coating the impact that China, India, and the former Soviet Union may have on jobs and incomes in America in coming years. Unless we find some answers, our children—and certainly our grandchildren—will be in for a very rough ride."

THE COMPETITIVENESS EQUATION— THE SUPPLY OF SCIENTISTS AND ENGINEERS

It should be emphasized that the goal of the National Academies' Gathering Storm committee was not to produce more scientists and engineers merely for the sake of filling employment slots. Scientists and engineers today make up only 4% of US employment; even doubling their number would in itself have a modest overall impact on the economy. Rather, the point is that scientists and engineers contribute disproportionately to the creation of jobs for the other 96% of the nation's workforce by generating knowledge, by innovating, and by establishing new companies based on that knowledge and innovation.

It should also be noted that the Gathering Storm committee's intense focus on science, mathematics, and engineering was in no way intended to diminish the importance of other academic skills that are critical for survival in a knowledge world, with reading being foremost among these "other" skills. (In the most recent international test, US 15-year-olds ranked in 17th place in reading literacy.) The committee's emphasis on science, mathematics, and technology is merely a reflection of the growing pervasiveness of these fields in creating jobs and solving other societal problems, of the precarious state of today's K-12 education in the United States in these fields and, of course, of the National Academies' own principal expertise.

Although the nation will need a cadre of extraordinary people well versed in such fields as microbiology, information sciences, and nanotechnology—"bio, info, nano"—

such people will represent a relatively small part of the nation's employment base. The remainder of our citizenry will need to be sufficiently science-literate to survive and contribute in the high-technology world we are all entering. British novelist C.P. Snow used to delight in asking acquaintances whether they could describe the Second Law of Thermodynamics. When they failed, as they almost invariably did, he would point out that his question was the technologic equivalent of asking, Have you ever read any Shakespeare? In the same vein, Walter Isaacson, president of the Aspen Institute, has observed that "scientific illiteracy is sometimes worn as a badge of pride. Most educated people would be ashamed to admit they didn't know the difference between Hamlet and King Lear, but they might jovially brag that they don't know a gene from a chromosome or relativity theory from the uncertainty principle." Admittedly, not everyone *needs* to be a rocket scientist (most of them, incidentally, are engineers, not scientists!), but everyone will need at least to be functional in using basic mathematics and science and as familiar with a computer as their parents were with an automobile.

Engineers and scientists are, admittedly, not always particularly helpful in making that necessity a reality. Software programmers are notorious in this regard, having developed an entire "language space" of their own, speaking whole sentences without using anything but acronyms. In fact, most engineers don't even know what words many of the common engineering acronyms they use, such as "laser" and "radar," represent. Engineers design computers so that often we must click on "*start*" to turn them *off*. We must press the "*All On*" button to *turn off* our television set remotely. I adhere to the principle that normal people believe "if it ain't broke, don't fix it," whereas engineers believe "if it ain't broke, it doesn't have enough functions yet." Whatever the case, this is life in the fast lane, the *only* lane in the world in which we live, and those who cannot keep up seem destined to become road-kill on the information highway.

Despite the unprecedented explosion of scientific knowledge that has occurred in recent decades and its pervasive impact on our lives, a 2004 National Science Board survey revealed that almost 30% of America's adults do not know that Earth revolves around the sun, 22% do not know that the center of Earth is very hot, and over half do not know that electrons are smaller than atoms. Only half the population is aware that dinosaurs and humans never coexisted. Another poll indicated that at least 25% of American adults believe in astrology—no doubt more than believe in the principles of astronomy. And, according to a NASA survey, fully 15% of America's adults do not believe that humans have gone to the moon.

The not-too-astounding conclusion of the National Academies competitiveness study is that in a knowledge age we will need people with knowledge. And we will need a few

people with extraordinary knowledge, particularly in science and engineering. Nobel laureate Julius Axelrod was probably guilty of understatement when he observed that "99% of the discoveries are made by 1% of the scientists." It would seem that one cannot make up for the lack of an Einstein with legions of less-capable scientists.

But the trends in America's scientific and engineering workforce are not encouraging:

- During the past 2 decades, part of an era that has been described as science and engineering's greatest period of accomplishment, the numbers of engineers, mathematicians, physical scientists, and geoscientists graduating with bachelor's degrees in the United States have declined by 18%. The proportion of university students achieving bachelor's degrees in these fields has declined by almost 40% during that time.
- Almost twice as many bachelor's degrees were awarded in physics the year *before* Sputnik, deemed a time of dangerous educational neglect, as last year.
- The number of engineering doctorates awarded by US universities to US citizens dropped by 23% in the past decade.
- In 2002, Asian countries as a whole awarded 636,000 first engineering degrees, European countries awarded 370,000, and North America awarded 122,000.
- The US share of the global output of doctorates in science and engineering declined from 52% in 1986 to 22% in 2003.
- The United States ranks 17th among developed nations in the proportion of college students receiving degrees in science or engineering, a fall from third place three decades ago. It ranks 26th in the proportion receiving undergraduate degrees in mathematics.
- The share of doctoral degrees awarded by US universities in science, engineering, technology, and mathematics to US citizens dropped from 65% in 1987 to 53% in 2005 (although the composition of this group was not uniform—for example, 84% of the degrees in psychology go to US citizens).

- In a recent contest of college software programmers, only two US universities' teams were in the top dozen finishers. Until the past few years, US universities dominated the demanding test.
- Fewer than 15% of US high-school graduates have sufficient mathematics and science credentials to even begin pursuing an engineering degree.
- There are more temporary residents than US citizens enrolled in graduate-level information-technology pursuits in US universities.
- Since 1982, a period during which the cost of living increased by 95%, the net cost of higher education (base cost minus grant aid) increased by 375%—even outstripping the increase in the cost of medical care (223%).
- According to Department of Education statistics, the United States is graduating more visual-arts and performing-arts majors than engineers.
- The US ranks eighth in the fraction of its citizens obtaining college degrees (in *all* fields).
- According to the National Bureau of Statistics of China, the number of students enrolled in higher education in China at the graduate and undergraduate levels each increased by a *factor* of 5 over the most recent decade.
- Although the United States ranks fifth among 27 developed nations in the proportion of college-age youth who enter college, it ranks 16th in the fraction of those who complete college (with a bachelor's degree or equivalent).
- According to Nobel laureate Richard Smalley, by 2010, 90% of all scientists and engineers with PhDs will be living in Asia.
- China graduates more English-speaking engineers than the United States.

Estimates of the numbers of various types of engineers being produced in China vary widely. One apparently conservative estimate states that in 2003 China graduated about 350,000 engineers, including computer scientists and information technologists, with 4-year degrees, and the United States about 140,000. If one considers only traditional engineering degrees, the comparison becomes about 250,000 vs 60,000. Similarly, China graduated 290,000 students with 3-year degrees (including computer scientists and infor-

mation technologists), and the United States about 85,000 with *either* 2- or 3-year degrees. According to Adnan Akay using data from the National Science Foundation, "The number of new PhD graduates in engineering in the US between 1983 and 2003 increased by 89%" (with most of the increase being foreign students) "while in Japan the increase was 204%, in South Korea 1858% and in Taiwan 4586%. The number of engineering PhD graduates in China increased 306% in only eight years."

Such comparisons are difficult to derive because of fundamental differences in educational systems in various countries around the world. For example, is an engineer who studied 3 years for 11 months each year less of an engineer than one who studied 4 years for 8 months each year? Most US universities' academic year for classes comprises only about half the weeks in a calendar year. Debating the nuances of the issue seems to offer about as much enlightenment as arguing how many engineers can dance on the head of a pin. But the forest seems abundantly clear, if not each individual tree.

Comparative data on the combination of science *and* engineering degrees are even more uncertain. *The Economist* reports that India graduated 690,000 scientists and engineers of all types while China produced 520,000 and the United States 420,000. By any measure, America's position is eroding rapidly. The operative question is, What will be the end state? Speaking to a group of political leaders in our nation's capital, Jeff Immelt, CEO of General Electric, shared his opinion on the topic: "We had more sports-exercise majors graduate than electrical engineering graduates last year. If you want to become the massage capital of the world, you're well on your way."

Punctuating that perspective, China's President Hu, speaking of the role of technology, recently stated that "the worldwide competition of overall national strength is actually a competition for talents, especially for innovative talents."

The supply of scientists and engineers does not affect only the competitiveness of acknowledged high-technology companies, such as Intel, Merck, and AOL. Consider the words attributed in the Forbes CEO Forum to Fred Smith, CEO of FedEx: "As FedEx grew, it had to become a technology company as much as a transport company." Also consider Procter & Gamble, perhaps best known for its diapers, soap, and toothpaste. Two of the most recent CEOs of that company have each described the firm as an R&D company, and its head of R&D has publicly stated that over the next 5 years, three-fourths of the firm's projected growth depends on advances in science and engineering. It has been amply demonstrated that if a firm loses its lead in innovation, it can lose market share in diapers just as fast as in jet engines.

Given the immense population disparities among nations, America cannot reasonably hope to produce the same number of engineers as, say, China or India. Nor does it need to do so. What is needed is not more engineers capable of performing relatively routine engineering functions—those jobs have already been commoditized and will continue to move abroad—but more engineers capable of creative, innovative thinking, engineers who can challenge the status quo and "see around corners," engineers who are entrepreneurs, and engineers whose ideas are bounded only by a solid understanding of the fundamental physical laws of nature.

The balance of power in science and engineering can tip rapidly. Craig Barrett, chairman of Intel Corp., has pointed out that 90% of the products that his firm ships on December 31 generally did not even exist on January 1 of the same year, and the pace of innovation continues to increase. It took 38 years to install indoor toilets in half of America's homes, 30 years to electrify half the homes, 25 years to place radios in a corresponding share, 7 years for television, and so on.

It is not difficult to convince me, as but one person, of the speed at which technology advances. I began my career using a slide rule—three sticks of wood and two pieces of glass—to perform engineering calculations, the middle of my career was punctuated by the landing of 12 of my friends on the moon, and the final phase of my career was shaped by something called the Internet. Yet nowhere in my experience have I observed anything approaching the revolutionary change that has taken place in much of China since the first of my visits to that country in the late 1970s. At that time, just 30 years ago, *all* adults—male and female alike—wore the obligatory "Mao suits." Hotels were few, cars and motorbikes were rare, bicycles seemingly everywhere, and the appearance of a Caucasian was cause for the gathering of large and curious crowds, particularly if the visitor happened to be carrying a Polaroid camera. Research laboratories were populated with primitive Soviet-style hand-me-down equipment; "clean" rooms had exposed concrete floors. To say that all that has changed would be an extreme understatement.

There are, of course, the "soft"—yet important—aspects of the science and engineering workforce issue: the social aspects. In one recent survey, when young Americans were asked whether they associated scientists with several pejorative terms provided by the pollsters, 70% of the respondents advised that they did. Geoffrey Orsak, of Southern Methodist University has written that "it is a sad reality that other young students from across the globe are clamoring to be admitted into engineering schools, yet US students who spend much of their day talking on cell phones created by engineers, driving cars

designed by engineers, and surfing the Internet made faster and more engaging by engineers, are passing [the profession] for other opportunities."

The attractiveness—or, more precisely, the unattractiveness—of a career in science or engineering, at least as seen through the eyes of much of America's youth, becomes evident when one examines trends in graduation statistics. The number of traditional bachelor of engineering degrees (excluding computer science) awarded by US universities each year has, as already noted, declined by 18% over the past 20 years. And the number of doctorates in engineering awarded to US citizens by US universities has declined by 23% in the past decade alone. In contrast, over the most recent 2 decades, the number of law degrees granted each year by US law schools has *increased* by over 20% and the number of master's degrees in business administration has increased by 108%. In absolute terms, the most recent data available from America's universities show nearly 44,000 students receiving law degrees, nearly 140,000 receiving MBA's, and over 64,000 receiving *bachelor's* of science in engineering and 6,400 receiving PhDs in engineering (of whom 33% are US citizens). In other terms, counting only US citizens, for every new (PhD) engineering researcher, the nation produces about one (PhD) physical scientist, 18 lawyers, and 50 MBAs. The implicit strategy seems to be to sue ourselves to prosperity, or perhaps to do so through *financial* "engineering."

In many countries, particularly developing countries, young people are eager to advance their lives through careers in science or engineering. These professions are viewed as ultraprestigious and, as has been the case in the United States, as entry professions for students who are in the first generation in their family to attend college (as was the case for me). In South Korea, 38% of undergraduates receive their undergraduate degrees in the natural sciences or engineering. In France, the corresponding figure is 47%; in China, 50% (the National Intelligence Council reports the figure for China to be 64%.); in Russia, 31%; in Singapore, 67%; and in the United States, *15%*. Correspondingly, of international graduate students attending US universities, about *70%* are majoring in engineering, physical science, life science, social science, or business.

In recent years, the number of US high-school students who expressed an interest in becoming scientists or engineers dropped from 36% to 6%. Today, fewer than 2% of US high-school graduates eventually receive engineering degrees from US universities (and very few study these fields abroad). In the case of women and minorities, the corresponding proportions are each less than 1%.

Craig Mundie, Microsoft's chief research and strategy officer, states that "if you ask most [US] kids when they're really young, what do you want to be, they're more likely to

tell you they want to be Tiger Woods or Britney Spears . . . than a scientist or engineer. When you go to China and ask that question, they actually answer Bill Gates." And Bill Gates himself warns, "We simply cannot sustain an economy based on innovation unless our citizens are educated in mathematics, science, and engineering." It might be noted that his cause was not aided by a recent full-page article in *The Washington Post* on how to get good grades in college. Number 2 on the list was "Don't major in engineering." According to *The Post*, college success "does not correlate" with "picking unusually demanding and precision-loving majors, particularly engineering, with exams that require the exact answer and not some lively written analysis of why exactitude is no longer applicable in a post-modern age."

In the United States, many engineers, including me, refer to *themselves*, actually rather proudly, as "geeks" or "nerds." (Although most of us probably privately envy astrophysicist Neil deGrasse Tyson, a giant of both mind and body, who declares that in high school "I was a nerd who could kick your butt!") As was once said, "Be nice to nerds. Chances are one day you'll end up working for one!" In a brief moment of imagined grandeur, I once proposed creating a television series called "L.A. Engineer." Astronaut Neil Armstrong describes himself as "a white-socks, pocket protector, nerdy engineer." Most US youths can't name a single Nobel laureate (in *any* field), but they know who Snoop Dogg and Allen Iverson are. Similarly, most Americans have no idea who Bob Noyce or Jack Kilby or Bob Kahn is, even though these people arguably changed the lives of Americans as much as virtually anyone who lived during the past century. When a Harris poll asked Americans to name a living scientist, virtually no one was able to do so.

Part of this unfamiliarity probably stems from the fact that as they pursue their primary and secondary education, few American youths ever come into contact with a practicing engineer or scientist. It is indicative of that local nonprominence that a few years ago at a meeting of American university presidents and the presidents of seven Chinese universities, the US representatives were a Renaissance scholar, an economist, a political scientist, a linguist, a lawyer, and a mechanical engineer, and the Chinese delegation constituted of six physicists and an engineer.

George Heilmeier, a former director of the Defense Advanced Research Projects Agency (DARPA), recently wrote that when he visits Russia he especially likes to go to the movies. "In Russia," he explains, "the engineer always gets the girl!"

Therein lies yet another aspect of the problem: women receive only 20% of the engineering bachelor's degrees and 17% of the engineering doctorates awarded by US universities. Nearly half the nation's high-school physics students are female, yet women

make up only 18% of doctorate recipients in physics. Women constitute 46% of the US workforce, but only 23% of the science and engineering workforce. Members of underrepresented minority groups receive disproportionately smaller shares of science and engineering degrees. For example, blacks and Hispanics, each making up about 12% of the total US population, each receive fewer than 5% of the bachelor's degrees and doctorates awarded in those fields (recently there were encouraging signs of an up-turn).

The overall record reflects a serious loss of potential talent in a nation that is struggling to compete with much more populous nations in an intense global marketplace. Furthermore, the tendency of the above groups to avoid science and engineering pursuits will become an even greater handicap in the future in that blacks and Hispanics constitute an increasing fraction of America's population and women an increasing fraction of America's (overall) college graduates. In 1970, 24% fewer women than men received bachelor's degrees; today, 35% *more* women than men receive such degrees. In fact, the number of white male US citizens receiving PhDs in engineering has declined by about 40% in three decades.

To a great extent, America has been living off foreign-born talent in science and engineering for many years. For example, during the most recent 15-year period, over one-third of US scientists who received Nobel prizes were foreign-born. One-fourth of the degreed professionals in the entire US science and engineering workforce are foreign-born. Of the PhDs in the US science and engineering workforce, 38% are foreign-born. Significantly, of those under 45 years old, 52% are foreign-born. Of engineering doctorates from US universities, 67% are granted to non-US citizens, and 40% of US engineering faculties are foreign-born. Of America's science and technology "postdocs," 58% are not US citizens. Sixty percent of the finalists at a recent Intel Science Talent Search were immigrants or the children of immigrants—and 46% of the members of the US physics team and 65% of the top US scorers in the mathematics Olympiad were the children of immigrants.

The following list of surnames of speakers r*epresenting US universities* at a recent (2003) communications conference is suggestive of the contribution of immigrants and the families of immigrants to America's science community: Farhaug-Boroujeny, Zhou, Blum, Deng, Hu, Seyedi, Poor, Kuo, Cioffi, Ding, Wang, Zaman, Zhang, Song, Alouini, Li, Liang, Han, Wiegandt, Hwang, Negi, Goldsmith, Larsson, Giannakis, Huang, Haimovich, Reed, Saulnier, Wu, Toumkakaris, Gardan, Wang, Lin, Papandreou-Suppappola, Zhang, Xia, Arora, Ambati, Zhu, Liu, Li, Nassar, Zekavat, Kang, Gamal, Qin, Zhang, Garcia-Frias, Yu, Li, Mitra, Yu, Ouzzif, Li, Mumtaz, Yan, Digham, Zhang, Tureli, Roy, Kang, Wu, Toumkis, and Poovendran.

The year 2005 (the most recent year for which data are available) saw a moderate overall increase in doctorates awarded in science and engineering by US universities; however, the 1-year gain was almost entirely attributable to non-US citizens. A Nobel laureate at one major university told me that of 50 applications by students to conduct graduate research in his laboratory, 49 came from China. Only one came from the United States.

Not only are we dependent on the rest of the world for energy (two-thirds of our petroleum comes from abroad) and for financial capital (70% of the world's surplus savings now comes to the United States), we are also becoming dependent on others for our brains. Reflecting that fact, Sudha Ramachandran, writing in *Asia Times*, warns that "the US will have to accept that with Americans lagging behind in tech skills, its economy doesn't just need immigrant brain power, it is dependent on it."

Tom Friedman writes about his attendance at Rensselaer's 2007 graduation: "The foreign names kept coming—'Hong Lu, Xu Xie, Tao Yuan, Fu Tang'—I thought that the entire class of doctoral students in physics were going to be Chinese, until 'Paul Shane Morrow' saved the day. . . .My complaint . . . was that there wasn't someone from the Immigration and Naturalization Service standing [there] stapling green cards to the diplomas of each of these foreign-born PhDs." In fact, it can be responsibly argued that America's scientific enterprise would virtually cease to function without the foreign-born talent that makes up such a crucial part of it.

Translating the new scientific knowledge that this enterprise generates into products and jobs is the province of innovation and entrepreneurship, and in this realm immigrants have made equally great contributions. Examples over the years range from steel magnate Andrew Carnegie (Scotland) and publisher Joseph Pulitzer (Hungary) to Yahoo! cofounder Jerry Yang (Taiwan), Sun Microsystems cofounders Andreas Bechtolsheim (Germany) and Vinod Khosla (India), eBay founder Pierre Omidyar (France), Intel founder Andy Grove (Hungary), and Sergey Brin (Russia), who cofounded Google. Immigrants have created 25% of all venture-backed public firms in the United States and 40% of those in the high-technology manufacturing industry, although legal immigrants make up only 9% of the total US population. A recent survey conducted at Duke University shows that immigrants from India and China (mainland and Taiwan) alone were key founders of almost 30% of all Silicon Valley startups. This research, which covers the 1995-2005 period, shows that 52% of Silicon Valley startups were formed by immigrants. The predominant group in the earlier period was Chinese; during the latter period, Indians were most prominent. A further study conducted at the University of Colorado indicates that for every 100 foreign

students who receive science or engineering doctorates at US universities, 62 future patent applications result.

"Yahoo! would not be an American company today if the United States had not welcomed my family and me almost 30 years ago," says Jerry Yang.

Foreign applications to US graduate schools plummeted after 9/11, in part because of the implementation of more stringent visa controls, in part because of growing prosperity elsewhere in the world, and in part because of a perceived "less welcoming" America. With regard to the former, *Newsweek's* Fareed Zakaria writes that "every visa officer today lives in fear that he will let in the next Mohammad Atta. As a result, he is probably keeping out the next Bill Gates." Zakaria might have added Wernher von Braun, Edward Teller, and Albert Einstein, to name but a few others.

Last year saw a 13% rebound in student and exchange visas granted as visa processes were modified, but applications by foreign students to US universities are still below the level of 3 years ago and enrollments from critical countries, such as India and Japan, continue to decline. David Heenan, the author of *Flight Capital*, calculates that several hundred foreign-born professionals *leave* the United States every day. In the case of China, returnees to their native country are referred to as "sea turtles" and make up a remarkable 81% of the membership of the Chinese Academy of Sciences. In some fields, such as particle physics, international meetings are now rarely held in the United States, because of uncertainties and delays in obtaining visas. Verne Harnish, the founder of Gazelles, an executive advisory firm for high-growth companies, is reported in *Fortune* as saying, "We're just not friendly any more."

Viewed from the perspective of the bright young foreign student, growing prosperity elsewhere in the world has opened a whole realm of possibility: "innovation without emigration." Opportunities for meaningful employment, as well as a high quality education, are markedly increasing in many parts of the world. At a recent National Academy of Engineering workshop, Theodore Rappaport, of the University of Texas, reported that of the 57 major research initiatives recently affecting the telecommunication field, all but five originated outside the United States. He believes that as a result US students have lost interest in entering graduate school to pursue research in the field. As though to punctuate his observation, CISCO recently announced that in the next 3 years it would be moving 20% of the positions held by its senior managers in Silicon Valley to Bangalore. Perhaps most astonishing, when asked in spring 2005 "What is the most attractive place in the world in which to lead a good life?," respondents in only one of the 16 countries polled answered "the United States." That represents a truly profound shift from views held during most of the prior century.

Many foreign countries are, in fact, intensifying their efforts to attract bright young international students. The Chinese Vice Minister of Education announced China's plan to provide scholarships for 11,000 foreign students in 2007 to augment the 140,000 international students said already to be studying in China. Singapore has indicated its goal to increase its foreign student enrollment from 70,000 in 2006 to 150,000 by 2012. Malaysia intends to boost the foreign student population in its universities from 70,000 in 2006 to 100,000 by 2010.

Further complicating America's increasingly tenuous competitiveness position, Congress a few years ago cut the annual allotment of visas for people with critical skills by two-thirds, from 195,000 down to 65,000, that is, to 0.02% of the US population. Meanwhile, an estimated 7-12 million people reside in the US illegally, and 50,000 immigrants arrive each year by virtue of a purely random drawing. In 2007, the fiscal year visa quota for immigrants with critical skills was filled 5 months before the fiscal year even began.

Perhaps the greatest irony of all is that to obtain a student visa to enter the United States, a foreign national must *promise to return home after receiving his or her degree*—not infrequently to help some foreign employer compete against US firms. For candidates seeking a US student visa to state that they wish to study in the United States so that they can remain in America and start a firm that employs US citizens is a sure ticket to somewhere else. That is a consequence of Section 214(b) of the Immigration Act of 1952—(un)popularly known as the "go-away clause"—which specifies that visitors must prove to the satisfaction of a US consular official that they will *not* remain in the United States after they obtain their degrees from US universities—usually on scholarships originally funded by US corporations or private citizens.

Chad Holliday, the CEO of DuPont, offers a perspective that is not atypical of American business as a whole: "If the US doesn't get its act together," he warns, "DuPont is going to go to the countries that do." Jim Jarrett, vice president of Intel, echoes that sentiment: "We go to where the smart people are and there are smart people all around the world." And it is not only the business community that is taking such a stance. US investors are buying foreign stocks at an unprecedented rate, and US consumers are purchasing 40% of their cars from Asian-based companies. In one recent quarter, Toyota sold more cars than Ford in the United States. Even the new CEO of Ford drove a Japanese car . . . until he became CEO of Ford! Unions decry management's decisions to move plants abroad, but their members generally make purchases and investments on the basis of their personal judgment of best value, not country of origin.

Political observer Norm Ornstein writes in *Roll Call,* "A few years back I helped supervise a project to create a comprehensive software package for presidential [appointee] nominees to use to fill out all the disclosure and conflict-of-interest forms. The American software company doing the work could not complete it, and the only place we could go to get it done well and on time was Mumbai. The software engineers there did a great job—and ended up knowing more about the intricacies of the American executive branch nomination and confirmation process than most scholars who teach about it."

THE COMPETITIVENESS EQUATION— THE RESEARCH ENTERPRISE

It will be necessary to have more and better scientists and engineers, but that alone will not be sufficient to ensure America's ability to compete in the 21st century. Funds must be available to underwrite the efforts of scientists and engineers who decide to pursue careers seeking the new knowledge that in turn creates new jobs. The funds must provide for modern laboratories and instrumentation and must support the conduct of research itself. As President Bush observed, "It's research that will keep the United States on the cutting edge."

Although the research establishment in America remains extremely productive, ample warning signs are to be found in considering the future. For example,

- In 2004, federal funding of research in the physical sciences as a fraction of GDP was 54% less than in 1970. In engineering, it was 51% less.
- By the end of 2007, China and India will account for 31% of the global R&D staff, up from 19% as recently as 2004.
- The share of US post-doctoral scientists and engineers who are temporary residents has grown from 37% to 59% in two decades.
- In 2005, only four American companies were among the top 10 in receiving US patents.

- The National Intelligence Council reports that in 2003 "foreigners contributed 37 percent of the research papers in *Science*, 55 percent in the *Journal of Biological Chemistry*, and 71 percent in the journals of the American Physical Society."
- For the first time, the world's most powerful particle accelerator does not reside in the United States; this virtually ensures that the next round of breakthroughs in this fundamental discipline will originate abroad.
- In the recent ranking by the Organisation for Economic Co-operation and Development (OECD), the United States is in 22nd place in the fraction of GDP devoted to nondefense research.
- Federal annual investment in research in the physical sciences, mathematics, and engineering combined is equal to the *increase* in US health care costs experienced every 6 weeks.

The National Science Foundation (NSF) has indicated that it can now fund only one in five research proposals that it receives, the vast majority of which are deemed meritorious by peer reviewers. As funds have become more scarce, peer reviewers have been less inclined to allocate grants to younger researchers as opposed to more senior researchers with "safe" track records, even though history shows convincingly that the most significant scientific advances have been attributable disproportionately to younger researchers pursuing cutting-edge, high-risk science. The median age for first grants to individual researchers by the National Institutes of Health (NIH) has recently reached 42 years, and it should not go unnoticed that even greater risk aversion has evolved among many of those who fund research on behalf of US industry.

In contrast with the deteriorating situation in the physical sciences and engineering, America has in recent years made a substantial investment in the biologic sciences, doubling the federal budget for health-related research at NIH over a 5-year period. The impact of the increase in investment in understanding the causes and cures of diseases has been remarkable. However, this gain was eroded as inflation ate away at flat or even declining budgets in the years that followed the buildup—a trend that was reversed once again in the current year's federal budget. It is, of course, of the utmost importance that increases in the funding of the physical sciences are not accomplished at the expense of investment in the biologic sciences. It is noteworthy in this regard that advances in the biologic sciences, the physical sciences, and engineering have often been highly interdependent, and they are increasingly so. For example, it is said that the human genome could

not have been sequenced without the benefit of progress in computers and robotics, and modern medical imaging would not have been possible without advances in computers and mathematics. Correspondingly, promising new fuels could not have become serious candidate energy sources without accomplishments in biology and agriculture.

One might argue that investment in research should be the province of industry because industry is often a principal beneficiary of research and its direct descendant, innovation. In fact, during the past 40 years, as the fraction of the nation's R&D spending provided by the government steadily declined from two-thirds to one-third, industry made up the difference, increasing its share of the total investment from one-third to two-thirds. Significantly, however, the composition of industry's effort changed markedly during this period: development, not research, became industry's priority. Although overall federal investment in research in constant dollars has been increasing, the growth has almost entirely been focused on the life sciences.

There are several reasons for industry's perhaps counterintuitive behavior. First, there is the inherent possibility that an investment in research may produce no new knowledge at all; research is a risky business. One study in information technology concluded that only one new research "idea" in 500,000 results in a commercially profitable product. Furthermore, even when an effort is successful, there may be uncertainty as to the applicability of a particular research project to a firm's own competence and business interests. For example, while working in the composites laboratory of an aerospace company—the same firm at which I was later employed—Howard Head conceived the idea for the skis and tennis racquets produced by the firm that now bears his name. The return to society as a whole from investment in research often far exceeds the rewards to the corporate underwriter or performer of an individual piece of research.

In addition to the implicit riskiness and uncertain applicability of investment in basic research, there is always the matter of its long-term nature, not uncommonly involving a decade or more of effort before results can be introduced into the marketplace. That constitutes a significant deterrent to investment by industry, which tends to have a "next-quarter" focus.

One might ask, Isn't that short-sighted? The answer, of course, is yes; it is very short-sighted. But before condemning industry, consider the following incident that occurred a few years ago at the company where I was employed. Motivated by an unusually large stable of highly promising research opportunities, the company's management conducted a briefing for Wall Street analysts to inform them of a planned increase in investment in research and the promise this would offer for the company's future growth and profitabil-

ity. At the end of the briefing by the company's president, most members of the audience ran from the room and sold the firm's stock. The company's share price dropped by 11% during the next few days, then gradually declined for nearly 2 years before the tide could be stemmed. When, shortly after the debacle on Wall Street, as the event became known in the company's research laboratories and executive suite, I asked one of the attendees at the briefing what had been said that was wrong, the analyst impatiently responded, "You should know that it takes 10 or 15 years for research to pay off . . . if it does at all. Your average shareholder owns your stock for about 18 months, doesn't care what happens to you 10 or 15 years from now, and certainly doesn't want to pay for it. In fact, by that time the investor will probably own one of your competitors' shares and would be just as happy if your firm were *not* competitive." The analyst then administered the coup de grâce, explaining, "Our firm does not invest in companies with such short-sighted management."

Is that one example of excessive focus on short-term profits at the expense of long-term substantive gains in the provision of goods and services perhaps simply an anomaly? To obtain insight into the answer to that question, consider a result of a survey by the National Bureau of Economic Research: 80% of the senior financial executives questioned said they would be willing to forgo funding R&D to meet their public projections of near-term profitability. Then consider that the outstanding value of derivative contracts worldwide recently reached 8 times the value of all the homes and land in the United States and over 5 times the combined yearly output of all the world's nations. Patience does not seem to rank highly on the list of attributes of today's investors, nor does making money "the old-fashioned way."

Margaret Thatcher eloquently summarized the significance, as well as complexities, of basic research in her remarks on the overall topic of innovation:

> Although basic science can have colossal economic rewards, they are totally unpredictable. And therefore the rewards cannot be judged by immediate results. Nevertheless, the value of Faraday's work today must be higher than the capitalization of all shares on the stock exchange. . . . The greatest economic benefits of scientific research have always resulted from advances in fundamental knowledge rather than the search for specific applications. . . . Transistors were not discovered by the entertainment industry . . . but by people working on wave mechanics and solid state physics. [Nuclear energy] was not discovered by oil companies with large budgets seeking alternative forms of energy, but by scientists like Einstein and Rutherford.

It has long been recognized that pursuits that are important to the public interest, but have disproportionately large societal returns as opposed to individual returns, often

of necessity become the province of government. But in the case addressed herein, US federal support of research in the physical sciences, mathematics, and engineering—when adjusted for inflation—has been stagnant for 2 decades. As already noted, as a percentage of GDP, federal investment in research in the physical sciences and engineering has been reduced by more than half since 1970. The federal government not only will need to increase its investment in research but also will need to find a way to forge closer ties among industry, academe, and government. That will require working arrangements to overcome such inherent barriers to cooperation as industry's 3-month rhythm (until the next quarterly report) vs academe's 6- or 8-year operating time constant (the period typically required to qualify for a PhD); academe's culture of "publish or perish" vs industry's "publish *and* perish" mentality; and government's periodic attacks on both academe and industry generally concerning overhead ceilings, visa policy, and antitrust matters, the latter including such assaults as the one courageously and successfully challenged in court by MIT several years ago.

Even when undertaking all reasonable steps to remain competitive in science and technology, it is unlikely that on the flat earth any nation, even one as wealthy as the United States, can maintain a position of such broad prowess as the United States has enjoyed in recent decades. A few areas can undoubtedly be singled out in which to seek prominence, more areas can be pursued wherein a nation can be a "fast follower" in applying new knowledge, and still more will simply have to be monitored or even forgone. That is, choices must be made—and these will be difficult choices bearing significant consequences. Those making such decisions will no doubt seem to face the sort of dilemma that comedian Woody Allen once described in the following terms: "More than any other time in history, [we] face a crossroads. One path leads to despair and utter hopelessness. The other, to total extinction. Let us pray we have the wisdom to choose correctly!"

The decline in support of basic research in America has been particularly pronounced in the case of the Department of Defense (DOD), an organization that for the latter half of the 20th century was arguably the pivotal underwriter of basic research and innovation in the nation. Examples of commercial products stemming from research investment by DOD are as varied as the Internet, freeze-dried foods, weather satellites, GPS, communication satellites, and nuclear power. But during the past 30 years, the fraction of overall defense research, development, test, and evaluation funds devoted to science and technology has dropped, from 20% to 13%. Real funding of basic research by DOD has been essentially flat for 30 years in spite of the growing overall defense budget and the growing importance of technology to national security. Its science and engineering workforce

declined from 45,000 to 28,000 during the 1990s alone, according to testimony before Congress by DOD officials.

Competitiveness problems are exacerbated when national security is addressed—a realm wherein scientific and engineering leadership—or lack of leadership—can have profound consequences. President Bush, echoing the sentiments of several presidents speaking of their own eras, noted that "science and technology have never been more important to the defense of the nation and the health of the economy." In the aerospace industry, most engineers and scientists require security clearances, the granting of which generally demands US citizenship. During my service as CEO of the Lockheed Martin Corporation, that firm employed over 80,000 scientists and engineers. The defense establishment cannot simply outsource its software to a shop somewhere in Bangalore, as many commercial firms can and do. Executives at several US government organizations have told me that whereas they used to go to US universities and companies for information about leading-edge technologies, they now find that they increasingly must go abroad.

The recent century's most decisive new military capabilities—such as the atomic bomb, night vision, stealth, digital computers, precision-guided missiles, nuclear propulsion, precision geolocation, space surveillance, and the airplane—all had their roots in new discoveries and innovation.

America's national security challenge has been complicated by the ongoing transition of the nation from a manufacturing economy to a service economy. Today, fully 77% of America's jobs reside in the service sector, which is in general not the arsenal of military might. It may be possible to base a prosperous society on a service economy, but a nation cannot successfully fight a major conflict purely with a service economy. Armored vehicles, missiles, airplanes, sensors, and communication satellites are still among the instruments of survival and success in modern combat, not the production of reality television programs, sports extravaganzas, mass-media exposes, audits, and legal depositions. And finally there is the all-important underlying issue that a weakened economy may simply be unable to *afford* the resources needed to defend itself and its interests. The Soviet Union imploded in trying to provide an immense defense capability with an undernourished economy.

Several years ago, *before the events of 9/11*, Congress established what became known as the Hart-Rudman Commission, of which I was a member, and assigned it the task of examining America's national security needs in the decades ahead and making any recommendations deemed appropriate. It was assumed by the mass media and many others interested in the effort that the group's findings would concern the number of air wings,

infantry divisions, and carrier battle groups that the nation should maintain to prevail in possible future conflicts. Instead, in its two (sadly prescient) major findings, the bipartisan group warned that a major terrorist attack would probably take place on US soil and produce thousands of casualties, and stated that "the inadequacies of our system of research and education" pose a threat to national security "greater than any potential conventional war that we might imagine." It noted that, "second only to a weapon of mass destruction detonating in an American city, we can think of nothing more dangerous than a failure to manage properly science, technology, and education for the common good."

THE COMPETITIVENESS EQUATION— THE INNOVATION ECOSYSTEM

In our hypothetical board room, with the need to decide where to locate a new facility, the focus thus far has been on labor costs, the availability and quality of human capital, and the creation of knowledge. But other ingredients will affect where new plants, offices, and laboratories—and the jobs they provide—are to be. This so-called innovation ecosystem, a combination of factors defining the "innovation-friendliness" of a country, plays a large role as managers and boards decide where to locate new facilities.

One such factor—arguably of declining importance—is the proximity of potential customers. Between 2012 and 2020, China will pass the United States to become the largest consumer market in the world. By 2030 China alone is expected to have more middle-income consumers than the entire population of the United States at that time. India's middle class is projected to grow from today's 50 million citizens to just under 600 million by 2025.

Another factor affecting the selection of a location for a new business venture has traditionally been the availability of investment capital. America has long enjoyed an immense advantage. California alone has far more venture capital than any *nation* on earth (other than the United States). This is rapidly being neutralized because financial capital now crosses porous geopolitical borders literally at the speed of light as it chases opportunity. In 2005, for the first time in 20 years, US investors put more new money into international stock funds than into US stock funds and did so by a substantial margin. As

recently as 6 years ago, only 8% of the money newly invested in US stock funds went overseas; now the fraction has reached 77%.

There remain a number of other factors in the US innovation ecosystem that might lead firms to locate new facilities elsewhere. For example,

- The US effective corporate tax rate of about 40%, including state taxes, is, according to the Tax Foundation, higher than that of all but one other developed nation. Exacerbating the problem, most US corporate taxes, unlike those of many other nations, apply to *global* earnings. For example, a US firm competing in Ireland has imposed on it a 35% net US federal tax rate, whereas an Irish firm pays 12.5%—which was reduced from 50% as Ireland successfully girded itself for the global economic race. Many nations offer "tax holidays" for a specified period when new entities establish themselves within the nations' borders. In the early 1990s, the United States ranked first among OECD nations in offering tax incentives for R&D; but by 2004, it had fallen to 17th place. Perhaps the most significant factor in this regard is the federal R&D tax credit that requires renewal by Congress and the president each year and is therefore unreliable and diminished in value to companies addressing the long-term decisions implicit in the conduct of R&D.

- The US patent system is in many respects antiquated. In the words of Michael Splinter, CEO of Applied Materials, Inc., "Those of us who are patenting inventions are becoming hostages to those who are inventing patents. The current system is an invitation to litigation." It seems that the jobs that our patent system is creating are largely for lawyers, not scientists, engineers, and entrepreneurs and those they serve.

- US firms are among the few that directly bear the responsibility for funding major portions of the health care received by their employees, their employees' families, and their retirees and their families. That is an admirable social practice, but the cost of providing such benefits must be recovered in the prices that the firms charge for their products or services. It is not an immaterial cost: General Motors now spends more on health care than on steel; Starbucks spends more on health care than on coffee. Many executives responding to a recent PriceWaterhouseCoopers survey indicated that health-care costs, now 16% of the entire GDP, have had a "major impact" on the competitiveness of their businesses. The secretary of health

and human services, Mike Leavitt, observes that "there is simply no place on the economic leader-board for a nation that spends a fifth of its domestic product on health care."

- Similar considerations are related to employer-provided pensions. Bethlehem Steel in 2001 celebrated its impending 100th birthday by declaring bankruptcy. The number of workers that the firm employed during World War II had dropped by a *factor* of 27 by the time the company was liquidated in 2004, down to 11,000. But, the company had over 5 times that many pensioners on the roles still drawing benefits from the firm. Similarly, General Motors supports three pensioners for every worker now on the payroll. *Time* magazine offers the following summary: "Dig through the financial statements of the Detroit Three . . . and you can easily conclude that they are money-losing retirement and healthcare organizations just masquerading as money-losing carmakers." But perhaps most troubling of all, the lack of portability of most pensions will make them almost irrelevant to the needs of the average worker in an increasingly turbulent job market.

- Finally, as previously noted, and perhaps most astounding of all, US industry consistently spends three times more on litigation than on research. This is in part attributable to the malfeasance of some business leaders who abuse their fiduciary responsibilities and in part to the actions of some members of the legal profession who exploit the vagaries of the judicial system for their personal gain. Whatever the cause, the result is clear, and it is not a formula for survival in the emerging, intensely competitive world.

It is presumably because of such considerations that only 41% of the global corporations responding to a recent survey ranked the United States as an "attractive" location for new R&D facilities, compared with 62% for China. This, of course, represents a remarkable shift.

Perhaps the most incisive summary to be found, as far as the nation's competitiveness ecosystem is concerned, comes from the 2,500-year-old writings of Aeschylus:

So in the Libyan fable it is told

That once an eagle, stricken with a dart,

Said, when he saw the fashion of the shaft,

"With our own feathers, not by others' hands,

Are we now smitten."

GONDWANALAND LIVES!

Geologists tell us that some 200 million years ago many of the earth's major continents were joined together in a single "supercontinent" known as Gondwanaland. It included, in part, what is now South America, Africa, Australia, Antarctica, Arabia, and the Indian Peninsula. Over time, the continents slowly drifted apart, with their influence on each other diminishing correspondingly. The last few decades have seemingly brought all the continents crashing back together again. A problem encountered with the economy in Southeast Asia causes a stock market crash in Europe. A precipitous drop in the Chinese stock market—"The Shanghai Surprise"—produces a significant decline in the US Dow Jones. The devaluation of the Russian ruble brings down the best known hedge fund in America. And so it goes in this modern version of Gondwanaland. Tom Friedman's previously noted remark that globalization has made Beijing, Bangalore, and Bethesda next door neighbors seems to have geologic as well as economic connotations!

It is tempting, especially for people who are disciples of Adam Smith (a group that includes myself), simply to dismiss the untidy competitiveness matter that results from this drift by saying, "Let market forces solve the problem." But, unfortunately, that *is* the problem—at least from America's perspective. Indeed, market forces *are* solving the problem. They are solving it by moving jobs outside the United States and by reducing or limiting compensation and benefits for employees who remain in the US workforce. Intel spokesperson Howard High explains: "We go where the smart people are. Now our business operations are two-thirds in the United States and one-third overseas. But that ratio will flip over in the next 10 years." Following the pattern of many other companies, Dell announced in 2006 that it plans to increase its workforce in India by a factor of 2; that is, to 20,000, within 3 years. Already, 125 of the US Fortune 500 companies have

established research facilities in India, and the R&D boom in China and elsewhere is also gathering momentum.

The irony is that "American" *companies* may well survive, and their owners even prosper, but market forces will cause this to be at the expense of America's *workers*. In such a scenario, America could evolve into a nation comprising a number of extremely wealthy shareholders (fully 55% of Finland-based Nokia's shares are owned by Americans) and a few corporate headquarters (at least for a time) mired in an enormous sea of unemployment. That is not a formula for stability, national security, or quality of life for most of America's future citizens.

Is it already too late? Is the contest, as some critics have suggested, already over? Is America's future now behind it? One observer, *Electrical Engineering Times*, recently provided the following assessment in the introduction to its annual State of the Engineer Survey: "The single, young, energetic, upwardly mobile engineer constantly angling for better pay and greener pastures was for decades a Silicon Valley stereotype. But that image no longer holds true. The go-getters are now in India."

In contrast, the National Academies and others believe that it is not too late, but they warn that it is *getting* late—very late. The good news is that we can do something about the competitiveness challenge, but only if we act with urgency and perseverance.

Less than 12 years after being surprised by Sputnik, America mobilized itself and placed the first of a dozen humans on the moon—and brought them all home safely. A similarly intense effort will be required if we are to give Americans the opportunity to hold high-quality jobs in the future. Other nations have faced serious competitive challenges and are doing something about them. Finland, Singapore, Portugal, and Ireland are prime examples. This past year, Portugal, in its overall environment of severe fiscal austerity, increased its investment in science and technology by 60%. In 1987, Ireland's Gross Domestic Product (GDP) per capita was 31% below the average of the European Union (EU). It was, by almost any measure, among the poorest countries in Europe. In fact, 1% of its population—including some of the youngest and best educated members of its citizenry—was leaving the country each year in search of opportunity. But by 2003, Ireland's GDP per capita had grown to 36% above the EU average; unemployment had fallen from 17% to 4% and young people were immigrating into Ireland from the rest of Europe to fill the new jobs being added at a net rate of 4% per year. Economist Dermot O'Brien describes this growth as "off the scale in European terms."

But except for those who *fail* to adapt, this is a race without a finish line, a race that

never ends. A few companies are now beginning to leave Ireland for greener pastures, such as Poland and Hungary, and Ireland is already taking steps to strengthen its competitiveness and attract them back.

How did Ireland do it? The answer is straightforward. They did it the old-fashioned way, the way America must do it and used to do it: "Get out and compete." The choice is straightforward: in the 21st century, a developed nation can either innovate or evaporate. It can invest in the future, or it can enjoy the present until the present becomes the past.

In fact, it is already widely agreed that the key to survival for countries suffering severe labor-cost burdens is innovation: being first to acquire new knowledge, being first to create new products and services derived from that knowledge, and being first to market new products and services. (As used here, *innovation* includes entrepreneurship.) With regard to the latter activity, even a few weeks can make an immense difference between success and failure, so it is all the more important that we not handicap ourselves further with unneeded bureaucracy, regulation, and oversight. In some respects, America is doing well in that regard, being one of the fastest and least expensive places in the world to start a new business. In others—such as visa processing, product licensing, resolution of judicial matters, and export approval—it lags behind much of the world.

How does a nation achieve success in innovation in science and technology? There are at least four prominent ingredients in the process. The first is to generate a supply of brilliant scientists capable of producing new knowledge. The second is to invest sufficient funds to support the research of those scientists. The third is to provide a cadre of engineers who have a solid understanding of the fundamental laws of the universe yet are capable of the unconstrained, imaginative, creative thought that translates newly discovered scientific knowledge into products and services. And the fourth is to create an environment that is highly conducive to innovation. The latter, as already noted, includes the availability of risk capital, a sound patent policy, a constructive tax policy, and reasonable liability laws. It also includes a number of less tangible factors. Seven of the latter are briefly described below:

The *first* is an environment that provides researchers and inventors the *freedom to explore*—an environment that offers creative, inquisitive people the opportunity to pursue promising new avenues that may appear unexpectedly in their research and to be rewarded for their successes. The classic example at least of the former would be Alexander Fleming's discovery of penicillin. It is said that this enormous contribution to humankind was brought about when Fleming, studying bacteria with his microscope, found that one of his slides had accidentally become contaminated with mold. He also noticed that

bacteria were not growing in the vicinity of the mold. That simple observation led him to pursue a new avenue in his investigation, which ultimately resulted in the production of penicillin. Had Fleming been working in an environment wherein each moment's activities were prescribed and freelance exploration was proscribed, it is quite likely that the invention of penicillin would have been left to others at a later time, to the detriment of those who were then in need.

In a similar vein, according to *Smithsonian* magazine, Percy Lebaron Spencer one day was standing near an operating magnetron in his radar laboratory at the Raytheon Company when he recognized that a candy bar in his pocket was melting. That observation led to the discovery of the microwave oven. (Apparently, Spencer didn't stand there very long!)

It is important at this point to note the observation of Louis Pasteur that "chance favors only the prepared mind."

The *second* element is an atmosphere wherein *disruptive ideas are welcomed*, not discouraged or dismissed. When Alexander Graham Bell offered his world-changing invention, the telephone, for a fee of $100,000 to the Western Union Company, at that time one of the giants on the American corporate scene, the company flatly rejected the offer. A memo dated in 1876 was later found in the files of Western Union dismissing the proposal on the following grounds: "This 'telephone' has too many shortcomings to be seriously considered as a means of communication." After all, what could a person with a telephone say that couldn't be said with Morse code?

It was Darryl F. Zanuck, of the motion picture company 20th Century Fox, who, on being exposed to a new device called television, remarked that it "won't be able to hold any market after six months. People will soon get tired of staring at a plywood box every night."

In contrast with those examples from the past is the modern semiconductor industry, which about every 2 years introduces a whole new generation of integrated circuits that largely destroys the market for the existing products.

Third is an environment that is *tolerant of risk*—not irrational, injudicious, intemperate, or "overly exuberant" risk but rather prudent risk based on considered judgments that offer commensurate payoffs. A classic example of the willingness to accept understood risks was an advertisement placed in a London newspaper in the early 1900s by Antarctic explorer Ernest Shackleton. It read, "Men wanted for hazardous journey. Small wages, bit-

ter cold, long months of complete darkness. Constant danger. Safe return doubtful. Honor and recognition in case of success." Inspired by this advertisement, thousands of would-be explorers sent applications to join the expedition.

Fourth is an understanding that *failures must not be unreasonably punished*. Researchers and entrepreneurs must have the freedom to fail. Of course, if failures are due to negligence, dishonesty, or any other form of malfeasance, that is an altogether different matter. Princeton University's former President Harold Shapiro put this notion in these words: "I do not recommend failure. Nor am I attracted to the idea that failure builds character. But the willingness to accept the risk of failure is one of the costs of leadership and therefore, the price of all success." Indeed, if failure is routinely punished, it is human nature to simply adopt a policy wherein no risks are taken—a policy under which it is likely that neither failure nor success will be achieved. But as Dean Kamen, the inventor of the Segway vehicle and numerous other items, reminds us, the lack of failure does not constitute success.

Fifth is an environment that produces and facilitates the search for discontinuities. Discontinuities—whether political, social, economic, technical, or other—are fertile grounds for innovators. In dealing with profoundly disruptive technology, it is noteworthy that history suggests that we generally overestimate the impact of a new technology in the short term and underestimate its impact in the longer term. Examples of the latter include the laser and the Internet, both of which were around for several decades before their broad impact was fully appreciated. A prime example of the former is represented in a quotation from Alex Lewyt, the founder and president of the home-appliance company that once bore his name, who informed us in 1955 that "nuclear-powered vacuum cleaners will be a reality within 10 years." Fortunately, he was wrong.

Sixth is an interactive environment wherein creative people can identify and pursue synergistic *cross-cutting technologies*—what University of Maryland Dean of Engineering Nariman Farvardin has described as "hyphenated engineering." Innovations are increasingly—but certainly not exclusively—being derived from the process of combining diverse technologies and disciplines, as opposed to mining of a single field in ever greater depth.

Seventh is the acceptance of the notion that those responsible for managing the innovation process must not run around pulling up the flowers, as the saying goes, to see whether their roots are healthy. *Patience, continuity*, and their close relative *perseverance* are all fundamental catalysts of successful innovation. Indeed, there is little that is easy about introducing change, that is, about innovating. Many difficult decisions are required,

many failures suffered, and a great deal of scar tissue almost invariably accumulated. As Thomas Edison once observed with regard to his efforts to find a suitable filament for the electric light bulb, "I have not failed. I have just found 10,000 ways that won't work."

The National Academies' *Gathering Storm* report on competitiveness provides an explicit plan to confront the competitiveness challenge facing America and its innovation enterprise. The plan consists of four overarching recommendations and 20 highly specific implementing actions. All are at the federal level because that was the charter of the Gathering Storm committee, but even more remains to be accomplished at the state and local levels. During the past year, several states have conducted Gathering Storm assessments of their own, and major convocations have been held at the state and national levels to address additional actions that could strengthen America's future competitiveness.

In the *Gathering Storm* report, the Academies' overall recommendations were coupled to the critical challenge of eliminating America's energy vulnerability (as opposed to "becoming energy-*independent*"—a virtually unreachable goal). There were several reasons for making that connection. First, the availability of a sustainable supply of reliable, clean, affordable energy is critical to the nation's economy and physical security and to the natural environment. Second, an attack on the energy-security problem happens to draw heavily on the same science and engineering fields that are currently in the greatest need of increased attention from a competitiveness standpoint: physics, chemistry, mathematics, and engineering. Third, an assault on energy vulnerability provides a focus and a framework for many of the recommendations in the report, much as the Apollo program to put humans on the moon provided cohesiveness to the national research and education reforms that followed the Soviet launch of Sputnik in 1957. The magnitude of the energy challenge to the nation is suggested by the fact that the United States, with only 5% of the world's population, consumes 25% of the energy commercially produced on the entire planet.

The Gathering Storm committee's four overarching, highly interdependent recommendations, in order of assigned importance, are:

I. Move the US K-12 education system to a leading position by *global standards*.

II. Double the real federal investment in basic research in mathematics, the physical sciences, and engineering over the next 7 years (while, *at a minimum*, maintaining the recently doubled real spending levels in the biosciences).

III. Encourage more US citizens to pursue careers in mathematics, science, and engineering.

IV. Rebuild the competitive ecosystem by introducing reforms in the nation's tax, patent, immigration, and litigation policies.

In support of those general recommendations, the National Academies offered 20 specific implementing actions:

❖ *"***10,000 Teachers Educating 10 Million Minds"** (focuses on K-12 education, the committee's unanimous highest priority).

- Provide 10,000 *new* mathematics and science teachers each year by funding competitively awarded 4-year scholarships for US citizens at US institutions that offer special programs leading to core degrees in mathematics, science, or engineering *accompanied by a teaching certificate*. On graduation, participants would be required to teach in a public school for 5 years and, one hopes, beyond that time by choice.

- Strengthen the skills of 250,000 *current* teachers by such actions as subsidizing the achievement of master's degrees and participation in workshops, and create a world-class mathematics and science curriculum available for voluntary adoption by local school districts throughout the nation.

- Increase the number of teachers qualified to teach Advanced Placement courses and the number of students enrolled in those courses by offering financial bonuses both to high-performing teachers and to students who excel.

❖ **"Sowing the Seeds"** (focuses on funding for research).

- Increase federal basic-research funding in the physical sciences, mathematics, and engineering by a real 10% each year over the next 7 years.

- Provide research grants each year to 200 early-career researchers, payable over 5 years.

- Provide an incremental $500 million per year for at least 5 years to modernize the nation's aging research facilities, with the expenditures overseen by a National Coordination Office for Research Infrastructure to be in the White House Office of Science and Technology Policy.
- Allocate 8% of government research funds to pursuits specifically chosen at the discretion of local researchers and their managers, with emphasis on projects potentially offering a high payoff even though accompanied by substantial risk.
- Establish an ARPA-E in the Department of Energy patterned after the highly successful DARPA in the Department of Defense but focused on major breakthroughs in energy security.
- Institute a Presidential Innovation Award to stimulate advances serving the national interest.

❖ **"Best and Brightest"** (focuses on higher education).

- Provide 25,000 competitively awarded undergraduate scholarships each year of up to $20,000 per year for 4 years in the physical and life sciences, mathematics, and engineering for US citizens attending US institutions.
- Provide 5,000 competitively awarded portable graduate fellowships each year of up to $20,000 per year in fields of national need.
- Grant tax credits to employers that support continuing education for practicing scientists and engineers.
- Continue to improve visa processing for international students.
- Offer a 1-year visa extension to PhD recipients in science, technology, engineering, mathematics or other fields of national need, grant automatic work permits to those meeting security requirements and obtaining employment, provide a preferential system for acquiring citizenship for those who complete their degrees, and repeal the mandatory "go-away" provision now in US immigration law.
- Offer preferential visas to applicants who have special skills in mathematics, science, engineering, and selected languages.

- Modify the "deemed export" law whereby faculty currently may be required to obtain export licenses to teach a technology class that includes a foreign student even if the material covered is unclassified.

❖ **"Incentives for Innovation"** (focuses on innovation environment).

- Adopt a "first-to-file" patent system and increase employment of the US Patent and Trademark Office to permit accelerated handling of patent matters.
- Expand and make permanent the R&D tax credit that has been extended 11 times since it was first enacted in 1981 but never made permanent.
- Restructure the corporate income-tax laws to help make firms that create jobs in the United States more competitive.
- Increase broadband Internet access throughout the nation.

Many of these recommendations have been tested on smaller scales and demonstrated to work effectively. For example, the highest-priority recommendation—produce mathematics and science teachers holding primary degrees in these fields—has been addressed by at least two privately sponsored, highly successful endeavors: UTeach and Teach for America. UTeach reports that 22% of its participants, on completing their undergraduate degrees, voluntarily go on to teach in high school. Even more significant, 82% of those who do so are still teaching 5 years later. Teach for America seeks volunteers to teach in the most challenging urban and rural schools (20% teach mathematics and science). The program has become one of the 10 largest employers on college campuses nationally. Last year 10% of the seniors at Duke, Amherst, and the University of Chicago competed for positions in the program, along with 7% at Princeton and Yale. An independent study by Mathematics Policy Research reports that Teach for America members "produced higher [student] test scores than other teachers in their schools—not just other novice teachers or uncertified teachers, but also veteran and certified teachers." When members staffed a school opened for children displaced by hurricane Katrina in New Orleans, initial testing showed the students were 1.7 grade levels behind in reading and 1.5 levels behind in mathematics, but after just 7 months of instruction by Teach for America participants the students gained 1.3 grade levels in reading and 2.0 in mathematics.

What will all the National Academies' recommendations cost? Can we afford it? The answer to the first question is $9 billion the first year, growing to $19 billion per year steady-state. The answer to the second question is that we cannot afford *not* to do these things or the equivalent. Last year, as a nation we spent $7 billion gambling on the Super Bowl. We devoted $13 billion to pornography. We spent $32 billion on movies and DVDs. We have a federal budget of $2.8 *trillion*, and a GDP of $13 *trillion*. The affordability of funding for education, research, and innovation is simply a matter of whatever priority we wish to assign to meeting the competitiveness challenge and offering our children and grandchildren the opportunity to enjoy a high-quality standard of living.

A NEW BEGINNING . . . OR A NEW END?

As action is sought in the political sphere to meet the nation's competitiveness challenge, it needs to be emphasized that competitiveness is not a partisan issue. It is an *American* issue. In fact, the initial bill introduced in the Senate to implement the National Academies' findings promptly acquired 70 cosponsors—35 Democrats and 35 Republicans—all in an election year. The fiscal year 2007 federal budget that was enacted in part through a continuing resolution, made special provisions for many of the recommendations offered in the *Gathering Storm* report. Similar steps have been taken with regard to the 2008 budget; for example, the bill that rectifies differences among the various competitiveness measures previously proposed in the Senate was cosponsored by the majority leader and the minority leader.

Votes on competitiveness measures have received overwhelming support in the House of Representatives. The final America COMPETES Act was passed by both houses and signed by the President in August 2007. Speaking in support of the initial competitiveness legislation introduced in the Senate after the National Academies' effort, Bill Frist, then Senate majority leader, noted that "authorizations for these programs would total $73 billion over the next 5 years; when we consider that over the next 5 years our economy will exceed $76 trillion—a [0.1%] investment for the future seems a small price to pay for our continued economic security and leadership in the world." Senator Lamar Alexander noted on the occasion when he introduced legislation to implement the *Gathering Storm* report's recommendations, "If we only spend money on war, welfare, Social Security, debt, hurricanes, disasters, and flu, we're not going to have an economy strong enough to pay the bill for those urgent needs."

There is, of course, little political gain in taking the lead in addressing challenging problems—even serious problems—that most of the public has not yet recognized to

be problems. Columnist David Broder, writing in *The Washington Pos*t under the title "Thankless Bipartisanship," put it this way: "On Monday, with few of his colleagues present and the Senate press galleries largely unoccupied, Sen. Lamar Alexander of Tennessee took the floor. 'Last week,' he said, 'while the media covered Iraq and [recently fired] US attorneys, the Senate spent three days debating and passing perhaps the most important piece of legislation of this two-year session.'" Broder went on to assert that "Alexander's larger point is that this is the model Congress and the president need to follow—if any of the major challenges facing the country are to be met."

Indeed, the constructive bipartisanship reflected, at least to date, in addressing the nation's competitiveness-jobs-quality of life issue poses an excellent example for the resolution of many challenges. Ironically, when the overwhelmingly supportive vote on competitiveness was occurring in the House of Representatives, the media made virtually no mention of the event. Instead, it focused almost exclusively on a partisan battle that was concurrently being waged on another piece of legislation.

Some rightfully question whether the actions proposed by the National Academies, even if fully implemented, will be sufficient or even significant. One can know the answer to that question only as time progresses, but the proposals are at least a beginning. What is clear is that to do nothing is an almost certain formula for a greatly diminished America. There remain a few observers who insist that there is in fact no competitiveness issue; that concerns such as those expressed here are overstated. One can only hope that these observers are correct. But it seems imprudent to gamble the future of the nation and its children on that possibility. As Churchill said of those who argued against defense spending in Britain after World War I claiming that future wars were impossible in the "more civilized society" then existing: "It would be a pity if they were wrong."

In my travels abroad, I have been astonished by the degree to which foreign officials are familiar with the National Academies' *Gathering Storm* report. Some are conducting similar reviews of their own competitiveness standing. The ultimate irony—it might be termed the Doomsday Scenario—would be if our efforts succeeded in motivating others to do more and then we ourselves did or sustained little.

This nation did not arrive in its increasingly tenuous competitiveness situation overnight, certainly not under any one political party's oversight or through any single ill-considered action. For example, it has now been fully 24 years since a prestigious national commission on education cited what it called "a rising tide of mediocrity" in the nation's public schools. The true measure of our commitment in this contest will be staying-power.

As has been noted, it is unreasonable to expect that in a broadly prospering world any single nation can maintain indefinitely the broad dominance that America has enjoyed in recent decades. But America can, if it wishes, maintain a position of considerable strength, overall prosperity, and constructive leadership. Furthermore, if America decides no longer to play a major leadership role, the perplexing question then arises, Who might do so? This should be of concern to all.

Although only the passage of time can offer certainty, the available evidence strongly suggests that America and the world are on the precipice of a change of seismic proportions—a tipping point—similar to the one that saw the fraction of American workers engaged in agriculture plummet from 84% in the early 1800s to eventually settle at about 1%. The primary differences between that shift and today's is that the current transition will take place on a global scale and will occur much more rapidly. And *no one* will be immune to its impact.

A Broadway show some years ago bore the provocative title, *Stop the World—I Want To Get Off*. Unfortunately, or fortunately as the case may be, this new world is not likely to stop, or even pause, for *anyone*. Perhaps, then, the best advice for *everyone* is offered in a poem by Richard Hodgetts:

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.

Churchill once said that you can always count on the Americans to do the right thing—after they have tried everything else. Reversing America's competitiveness decline is one thing we had better get right the first time.

AUTHOR'S BIOGRAPHICAL INFORMATION

NORMAN R. AUGUSTINE was raised in Colorado and attended Princeton University, where he graduated with a BSE in aeronautical engineering, magna cum laude, and an MSE. He was elected to Phi Beta Kappa, Tau Beta Pi, and Sigma Xi. Mr. Augustine chaired the National Academy of Sciences, National Academy of Engineering, Institute of Medicine committee that developed the report *Rising Above the Gathering Storm: Energizing and Employing America for a Brighter Economic Future*.

In 1958, he joined the Douglas Aircraft Company in California, where he worked as a research engineer, program manager, and chief engineer. Beginning in 1965, he served in the Office of the Secretary of Defense as assistant director of defense research and engineering. He joined LTV Missiles and Space Company in 1970, serving as vice president, advanced programs and marketing. In 1973, he returned to the government as assistant secretary of the Army and in 1975 became under secretary of the Army and later acting secretary of the Army. Joining Martin Marietta Corporation in 1977 as vice president of technical operations, he was elected as CEO in 1987 and chairman in 1988, having previously been President and COO. He served as president of Lockheed Martin Corporation on the formation of that firm in 1995 and became its CEO in January 1996 and later chairman. On retiring from 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 was chairman and principal officer of the American Red Cross for 9 years, chairman of the National Academy of Engineering, president and chairman of the Association of the United States Army, chairman of the Aerospace Industries Association,

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Mr. Augustine has received the National Medal of Technology and the Joint Chiefs of Staff Distinguished Public Service Award. He has received the Department of Defense's highest civilian decoration, the Distinguished Service Medal, five times. He is coauthor of *The Defense Revolution* and *Shakespeare In Charge* and author of *Augustine's Law*s and *Augustine's Travels*. He holds 22 honorary degrees and was selected by *Who's Who in America* and the Library of Congress as one of "Fifty Great Americans" on the occasion of *Who's Who*'s 50th anniversary. He has traveled in over 100 countries and stood at both the North and South Poles.

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