A Tribute to the Leadership and Inspiration of
Morgantown Native and West Virginia University Graduate

DR. CHARLES M. (CHUCK) VEST

September 9, 1941 – December 12, 2013

Six Charles M. Vest Presidential Addresses to the National Academy of Engineering Annual Conferences, 2007 – 2012

TransTech

2016 TransTech Energy Business Development Conference

Chuck Vest was a devoted advocate of "Making Value for America" through understanding customers, research-based innovations, design, advanced manufacturing, and service. These values motivate and inspire the TransTech Energy Research and Business Development Program.

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WVU President E. Gordon Gee

Dear Friends,

The six speeches in this booklet provide a glimpse into the wisdom, foresight, and commitment of Charles M. Vest – qualities that grew from his family and his childhood in Morgantown, West Virginia.

Dr. Vest's father, West Virginia University Professor of Mathematics Lewis Vest, inspired in his son a strong devotion to principles, academic excellence and professional responsibility. His mother, Louise Vest, was a source for his engaging personality; ready smile; devotion to family, friends, colleagues; and the joy he radiated and cultivated in others.

As you read through the six speeches in this booklet, given during Dr. Vest's presidency of the National Academy of Engineering, you will feel both his urgency about energizing American innovation and his faith that we can meet this critical challenge.

Dr. Vest recognized America's shortcomings in dealing with global competition and the seeming inability of our leaders to set strategy – exemplified by lack of clear energy and carbon policy, declines in educational achievement, lagging U.S. manufacturing and addressing deterioration of our nation's ability to compete for quality jobs.

However, his words do not end with concerns about shortcomings. Every page recommends bold actions that would enable us to develop new paradigms and solve critical problems. In short, Dr. Vest reminds us that we have choices. We just need to step up – to form alliances between government, industry and academia that meet today's challenges; to summon leaders with bold visions; and above all, to provide world-class education and training for our young people.

Toward the end of his tenure as NAE president, Chuck Vest convened and led an expert panel to develop a new framework for innovation, design and manufacturing – a framework to create value through understanding customers, research, development, design and service.

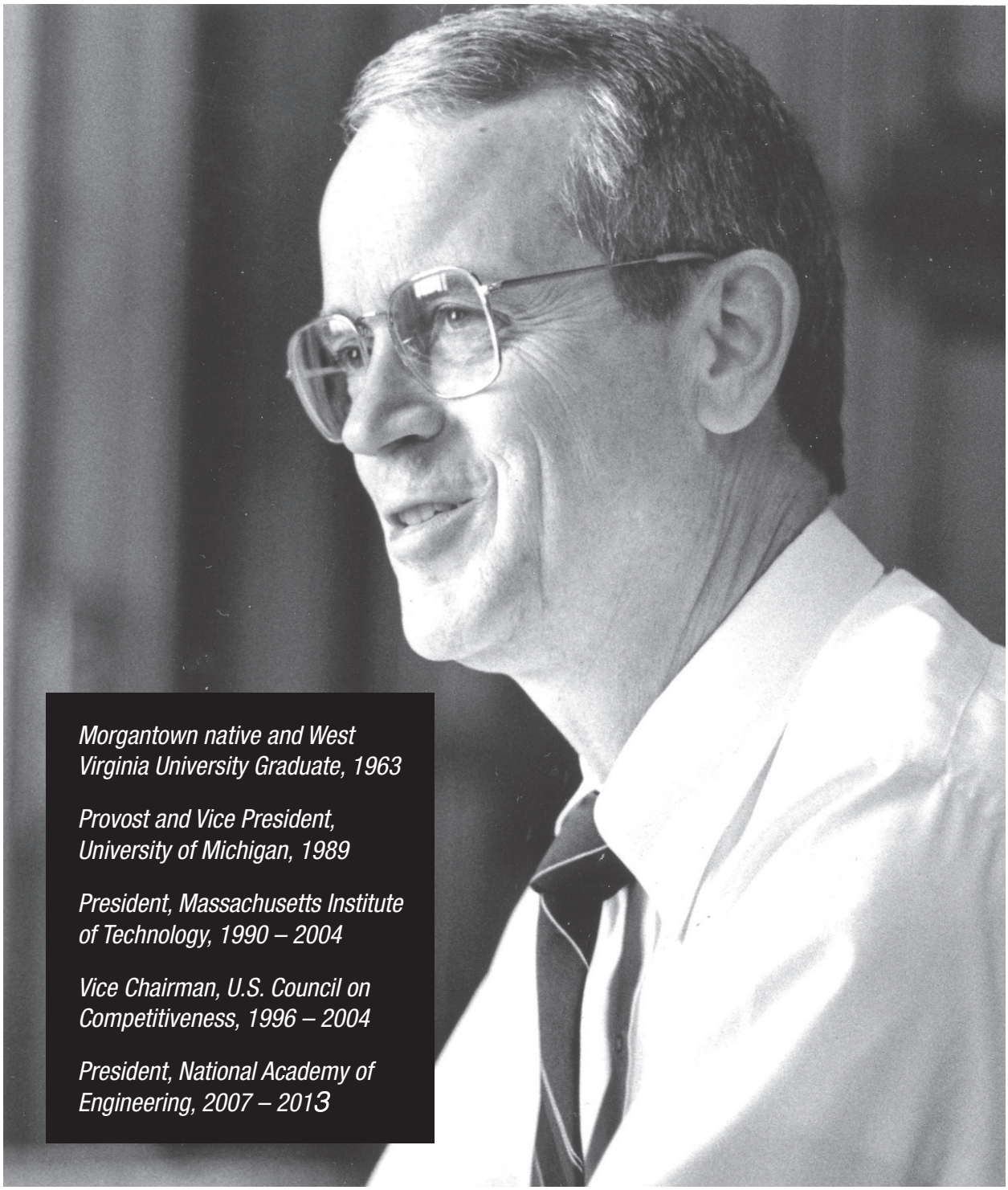
This framework lives on and has inspired positive actions such as the National Research Council's report and forums on "Research Universities and the Future of America: Ten Breakthrough Actions Vital to our Nation's Prosperity and Security;" NAE's ongoing study "Making Value for America: Embracing the Future of Manufacturing, Technology, and Work;" and the federal government's National Network for Manufacturing Innovation (NNMI), which will include up to 45 public-private institutes nurturing discovery and accelerating commercialization. I think Dr. Vest would be proud that WVU is a partner on the recently awarded NNMI Smart Manufacturing Innovation Institute.

I believe Dr. Vest's most powerful call for action came in the conclusion of his 2010 address "Technology and the Future of U.S. Competitiveness: Nightmares and Dreams." I hope all those who read his words will adopt Dr. Vest's ultimately positive vision. While changing the national agenda is not easy, Dr. Vest reminds us that it is possible – and that is our greatest source of hope for America's future.

Sincerely,

E. Gordon Gee

WestVirginiaUniversity.



Charles M. Vest

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CHARLES M. VEST BIOGRAPHY

Charles M. Vest was President Emeritus of the National Academy of Engineering and President Emeritus of the Massachusetts Institute of Technology.

Dr. Vest earned a B.S. in mechanical engineering from West Virginia University in 1963, and M.S.E. and PhD degrees in mechanical engineering from the University of Michigan in 1964 and 1967 respectively.

He joined the faculty of the University of Michigan as an assistant professor in 1968 where he taught in the areas of heat transfer, thermodynamics, and fluid mechanics, and conducted research in heat transfer and engineering applications of laser optics and holography. He and his graduate students developed techniques for making quantitative measurements of various properties and motions from holographic interferograms, especially the measurement of three-dimensional temperature and density fields using computer tomography. He became an associate professor in 1972 and a full professor in 1977.

In 1981 Dr. Vest turned much of his attention to academic administration at the University of Michigan, serving as associate dean of engineering from 1981-86, dean of engineering from 1986-1989, when he became provost and vice president for academic affairs. In 1990 he became president of the Massachusetts Institute of Technology (MIT) and served in that position until December 2004. He then became professor and president emeritus.

As president of MIT, he was active in science, technology, and innovation policy; building partnerships among academia, government and industry; and championing the importance of open, global scientific communication, travel, and sharing of intellectual resources. During his tenure, MIT launched its OpenCourseWare (OCW) initiative; co-founded the Alliance for Global Sustainability; enhanced the racial, gender, and cultural diversity of its students and faculty; established major new institutes in neuroscience and genomic medicine; and redeveloped much of its campus.

He was a director of DuPont for 14 years and of IBM for 13 years; was vice chair of the U.S. Council on Competitiveness for nine years; and served on various federal committees and commissions, including the President's Committee of Advisors on Science and Technology (PCAST) during the Clinton and Bush administrations, the Commission on the Intelligence Capabilities of the United States Regarding Weapons of Mass Destruction, the Secretary of Education's Commission on the Future of Higher Education, the Secretary of State's Advisory Committee on Transformational Diplomacy and the Rice-Chertoff Secure Borders and Open Doors Advisory Committee. He served on the boards of several non-profit organizations and foundations devoted to education, science, and technology.

In July 2007 he was elected to serve as president of the U.S. National Academy of Engineering (NAE) for six years. He has authored a book on holographic interferometry, and two books on higher education. He has received honorary doctoral degrees from eighteen universities, and was awarded the 2006 National Medal of Technology by President Bush and received the 2011 Vannevar Bush Award.

Source: https://www.nae.edu/Projects/Events/AnnualMeetings/2012annualmeeting/63542/26755.aspx

REFLECTIONS ABOUT CHARLES VEST | *by Kenan Sahin*

About Dr. Kenan Sahin…

Dr. Kenan Sahin is the founder and President of TIAX LLC and also its Chief Technology Officer. He is the founder and interim President of CAMX Power which formerly was a division of TIAX LLC and in May 2014 became a separate company. In 1982, he founded Kenan Systems with a $1,000 personal investment. The company became a world leader in telecommunications software, creating nearly 1,000 professional jobs. Dr. Sahin was named the Ernst & Young New England Entrepreneur of the Year in 1998. In 2003, the World Economic Forum named Dr. Sahin one of its 40 Technology Pioneers. He received the New England Business and Technology Association's first "Circle of Excellence" award in 2004. In 2006, he was given the Golden Door Award by the International Institute of Boston in recognition of his achievements as both an entrepreneur and an academic.

Dr. Sahin Offers These Reflections, Reminding Us of the Enduring Impact of Charles Vest's Life:

"I knew him throughout his presidency at MIT as I have been a life member of the MIT Board. In 2002 when I undertook an almost impossible project, I turned to him to be the Chairman of my Advisory Board. He graciously agreed as his MIT responsibilities allowed him to serve on only two Boards, IBM and DuPont. I had the benefit of his wise counsel for five years, until he stepped down from the presidency and became the president of National Academy of Engineering which organization would not allow any outside Board memberships.

He could have easily continued serving as the MIT president but when he privately gave me heads up on his impending decision to step down after fourteen years, he gave two reasons: He indicated that every baseball player thinks he has one more season in him until it is too late. Of course I believed and believe he had many more seasons. The operational reason he gave was that all five deans of MIT (all of whom he had appointed) were due to retire or step down and he simply did not want to be the one to choose the new ones and hence really shape the future of MIT. Such a modest man and he was and so impactful at MIT and elsewhere. Under his presidency, MIT plant increased by 25% and at least 25% of tenures were granted. And he guided MIT into its key role in life sciences, making Kendall Square the true hub of innovation with more startups than anywhere else in the world. Interestingly, he trained or mentored many future university presidents—close to ten I believe—e.g. Tufts, BU, Lehigh, Berkeley. On the national scene it is fair to describe him as the 'dean' of the university presidents. No one has been able to take on that role since his departure.

Another great MIT president, Howard Johnson, once observed that most leaders go from 'who is who' to 'who is he.' Chuck will always be on the 'who is who' list for the whole world."

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Charles M. Vest at work in the president's office at MIT.
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"It is time we regained our optimism and our 'can do' spirit so we can remain a great nation and meet the challenges of our time. The way to accomplish this is to reconnect what we do with what we dream. We need a country with more people dreaming about what's possible, where young people—no, all people—are inspired to imagine a better world and help make it a reality."

—Charles M. Vest

NAE's Mission To Provide Leadership

Charles M. Vest Presidential Address at the 2007 NAE Annual Conference

September 30, 2007

It is a great pleasure to participate in my first induction ceremony as president of the National Academy of Engineering (NAE), and a particular privilege to welcome the families, friends, and guests of those who are being inducted today as members or foreign associates of our academy. Your election to NAE signals that our members, through a very rigorous process, concluded that you are among the most brilliantly accomplished and distinguished members of your profession. We all hope that this is a deeply meaningful event in your personal and professional lives.

It is a beautiful day in Washington, the kind of day when it is refreshing and wonderful to be in this great city. Every time I think about Washington, D.C., my mind goes back to an incident recounted in Doris Kearns Goodwin's book, *Eleanor and Franklin*. During World War II, Winston Churchill traveled to this city to meet with President Roosevelt. London had been under a blackout since 1939, and Washington had been blacked out since a few days after Pearl Harbor. When Churchill's plane came in to land, Roosevelt ordered that all the lights in the city be turned on. I can only imagine the stunning effect of seeing this beautiful city suddenly light up. I cannot duplicate that feat for you, but we have gathered the great lights of engineering in the United States and are very proud to welcome all of you.

Election to NAE is a rare and singular honor, but membership is also an opportunity for national service. Indeed, it is a call to national service. We are chartered by the U.S. Congress, together with the National Academy of Sciences, the Institute of Medicine, and our joint operating arm, the National Research Council, to provide independent, objective advice to the federal government on matters of science, engineering, and medicine.

We are not a government organization, not part of the federal government. We are an independent, nonprofit organization that can be thought of as a grand think tank. In return for providing the objective, nonpolitical analyses and advice of the nation's most accomplished engineers, we have been granted a special, respected role as advisers to the nation.

We fulfill our function largely by conducting rigorous studies of specific issues, either requested by the government or, from time to

"In fact, our stark options at this moment are either to let fear of globalization—and of terrorism for that matter—become our national ethos or to revitalize our can-do attitude, our openness to the world, and our work ethic in order to lead in this challenging new century. Needless to say, I prefer the latter."

time, by initiating a study ourselves of an issue we believe is especially important. Of course, we call on our members to provide leadership for these studies. This is a primary service we will expect of you.

When I was elected to NAE in 1993, I received a note from John Armstrong, who is with us today. John was then vice president for science and technology at IBM. His note said, "Dear Chuck, congratulations on your election to NAE. I just can't wait to put you on a committee." So you see, John is less subtle in these matters than I am, but the message is the same.

A core mission of NAE is to look after the technological welfare of the United States. As Craig Barrett said earlier, engineering is critical to meeting the fundamental challenges facing us—challenges to our economy, environment, health, security, indeed, our way of life. Although industries are well aware of the centrality of engineering to the production of competitive products and the delivery of services in the world marketplace, governments at both the federal and state levels are struggling to understand and incorporate science and technology into public policies, some of which are literally matters of life and death.

As NAE members, participants in the world's most formidable think tank, an independent organization of more than 2,000 of the nation's most accomplished engineers, we can play, and must play, an important role in securing the nation's future. In my view, this is a form of engineering leadership.

Engineering Leadership

Interest in engineering leadership is growing around the country—in universities, in industry, and certainly here at NAE, through mechanisms such as the coveted Gordon Prize for Innovation in Engineering and Technology Education. But probably each of us means something different by the term "engineering leadership." So it is worthwhile to ponder its meaning and the qualities and actions we should seek in engineering leaders.

When I think of leadership, I focus on the definition of a leader I learned from our colleague Bob Galvin, the legendary former chairman of Motorola and an active NAE member. "A leader is one who takes us elsewhere." That definition not only sums things up but also reinforces my own belief that leadership can be exercised in many different ways and in many different domains of human activity, including those that involve engineering and technology. Leadership has many modes in addition to the usual command-and-control model. It seems to me that there is leadership *in* engineering, leadership *through* engineering, and leadership *informed by* engineering.

Leadership in engineering may have many different forms. The classic, and extremely important, mode of engineering leadership is through project management and product development. A number of engineering schools are developing innovative programs in these areas, usually in collaboration with industry and management schools, and many of you in this room are outstanding project managers.

But if we accept Bob Galvin's definition of a leader as one who takes us elsewhere, leadership in engineering can also take the form of outstanding execution, of discovery, of invention, or of refinement of products, services, and processes. Leadership can be exercised through excellent teaching and through innovation.

Leadership through or informed by engineering includes engineers as business leaders, as entrepreneurs, as politicians, and simply as concerned, active citizens. We are increasingly faced with political and societal decisions that cannot be made without serious engineering input. One need look no farther than the development of biofuels, which all of us, I suspect, agree is a good

thing. But we must also be aware of the combination of the politics of corn and farm subsidies, the absence of life-cycle analysis, and the lack of global perspective that are pushing us to develop biofuels in ways that make little technological or economic sense. This is an example of an issue in which government decisions should be informed to a great extent by serious engineering analysis and experience.

In my view, the source of leadership, particularly in professional settings, is respect for people and ideas. Without an understanding of others, their values, their aspirations, and their capabilities, it is very difficult to lead. If one accepts this view, then the source of engineering leadership should be respect for people, ideas, and "things," which may be physical objects that we design, produce, or modify, but may also be constructs like systems, projects, or networks. With respect for things, we can produce pleasing forms, efficiency, effectiveness, precision; use resources appropriately; and make wise choices among design options.

Leadership in the classical sense requires that we establish sound personal values. Developing and imparting such values are important goals of education, of culture, of family, of religion, and indeed of many other influences on young lives. Our values, whether or not we can clearly articulate them, guide our decision making and come into play, especially when, as leaders, we face difficult or stressful decisions.

But engineering leaders must have not only sound personal values but also technical expertise. Preparing our students or employees for leadership should not be thought of as something apart from fundamental engineering training and education. It is not an add-on. Leadership begins with sound engineering fundamentals and can be honed through group work, projects, and so forth.

Why have I sketched out these simple ideas? For one thing, leadership is a topic of increasing interest to engineering schools across the country. A more basic reason is that I believe these times call urgently for engineering leadership in all of its dimensions. NAE as an organization has a mission to exercise leadership informed by engineering.

Competing in the World Marketplace

As we enter the twenty-first century, the United States must attempt both to compete in the global knowledge-based economy and to maintain its prosperity and quality of life. To compete in world markets in this so-called knowledge age, we cannot depend on geography, natural resources, or military might. We will only thrive on brainpower, organization, and innovation. And we must do this through our loosely structured partnership among government, industry, and academia.

Frankly, I think we are about to be hit between the eyes by the full force of global competition and by the realization that many twenty-first century jobs will follow knowledge, innovation, and expertise wherever they exist in the world. Never forget that people everywhere are smart and capable, and, if given opportunities and education, they can achieve great things.

The only acceptable response in this situation is for us to lead. But leading will mean upping the national commitment to education and training at all levels and increasing investments by both government and industry in research, development, and innovation. Leading will require, above all else, inspiring and preparing a new generation of young people to explore and expand the frontiers of science and technology and to devote their energy and intelligence to solving the real problems we face, such as energy, environment, food, efficient delivery of health care, the shift toward a global service economy, and world security.

In fact, our stark options at this moment are either to let fear of globalization—and of terrorism for that matter—become our national ethos or to revitalize our can-do attitude, our openness to the world, and our work ethic in order to lead in this challenging new century. Needless to say, I prefer the latter. Our country is slowly awakening to these realities and challenges, but we are nowhere near having a sense of urgency about them. In fact, the enemy I fear most is complacency.

But there is some good news. We can celebrate that we are living, working, and learning at the most exciting time in science and technology in human history, a time when scientific discovery and engineering innovation are essential to advancing the human condition and creating a sustainable future. This is also a time of great change and the redistribution of intellectual and economic resources—a new century.

The New Century

In the last half of the twentieth century, when most of our careers played out, physics, electronics, high-speed communication, and transportation tended to dominate the agenda. In the early decades of the new century, it appears that biology and information will dominate, but priority must also be given to energy, water, and sustainability.

The new century has new distributions across the world of investments in research and development. North America, Asia, and Europe each contribute roughly one-third of the global investment in R&D. U.S. R&D, by almost every measure, is still on top, but it is losing share in every measurable category. This is understandable and good insofar as it represents a rise and improvement in the rest of the world. But U.S. declines could reach a tipping point, and that would be tragic.

The new century has new players. India leads in the number of young professionals in finance and accounting. By young professionals I mean college graduates who have up to seven years of experience in the workplace. China leads in the number of young professionals in engineering. The United States leads in the number of young professionals in the life sciences. But graduation rates indicate that China will soon dominate more dramatically in the sheer numbers of engineers.

The new century moves at a new speed. Look back for a moment and ask yourselves how long it took in the past for major innovative products or services to reach 25 percent of American households. The answer is interesting. It took about 55 years for the automobile to reach 25 percent of U.S. households after it was introduced as a consumer product. Fifty-five years in those days was almost a lifetime. It took 23 years for the radio to appear in 25 percent of U.S. households. That was almost a working career. It took only 8 years for 25 percent of U.S. households to have access to the World Wide Web. Many devices and processes, ranging from computing power and digital memory to the sequencing of genes and genomes, seem to be following some form of Moore's law. There is a steady acceleration to everything we do.

The new century features new jobs. More than 70 percent of American employment today is in the services sector, especially in information-based services. The fraction of employment in services has become essentially a measure of how well developed a nation is. Nonetheless, we all know how important it is for a country to also develop and produce things—physical devices and systems.

The new century has new connections. Tom Friedman has famously told us that the world is flat, that location no longer matters, and that many jobs are just a mouse-click away from any location on the face of the Earth. But the new century also has stimulated

new debates. There are those who argue strenuously that location does matter—because of the power of regional clusters of innovation, because of the importance of proximity of small companies and corporate laboratories to universities, and because many of our best venture capital networks have something of a local or regional focus.

The new century has new models of innovation. The term "open innovation," coined by Henry Chesbrough, has become very popular, and appropriately so. It means, very simply, that companies today must integrate the best ideas no matter where they originate and that new dynamic business models must be developed for this new, open, connected world. More work will be done in what many of you know as Pasteur's Quadrant, that is, research that not only advances fundamental knowledge but also addresses important technological problems. A well-known example is the research that led to the development of the transistor at Bell Labs.

The new century has new enterprise models. The CEO of IBM, Sam Palmisano, has written of what he calls "the globally integrated enterprise," which supersedes the multinational corporation. No longer will companies be clearly headquartered in a particular location with core activities, including research and development, conducted there, and manufacturing and marketing conducted in other places in the world. Instead, new organizations will be driven by globally shared technologies and standards. They will develop borderless strategies, borderless management, and borderless operations for integrated production and value delivery.

I believe we will begin to move away from the laissez-faire model implicit in Vannevar Bush's famous report, *Science, the Endless Frontier,* which describes how science and technology in this country move from research into the marketplace. For more than 60 years, we have been largely guided by a model in which the role of each partner in the loosely orchestrated network of our innovation system is reasonably clear. Young people study, learn, and then go off to the world of work. Researchers, whether in universities or industry, discover new facts about nature and invent new technologies. Legislators provide the funds to educate the young and support much of the research. And companies build on the talents and knowledge of graduates and their research results to produce products and services.

We now recognize that, as neat as that package is, each component of this innovation system has different expectations. Young people are drawn to science and engineering by curiosity, by awe of nature, by the excitement of discovery, and by fascination with the unknown. I hope this will always be the case. Researchers, as we all know, are driven by a fire in the belly and obsessive concentration on discovery and solving very complicated and difficult problems. Legislators believe that tax dollars should produce jobs, and companies want increasingly rapid innovation to drive up profits.

Whether we teach in universities or lead industrial organizations or are involved in making policy, we must understand these perspectives, expectations, and motivations and somehow meld them into a workable system to face the challenges of the acceleration and globalization of just about everything.

Frontiers of Engineering

These matters, I believe, are critical for our nation. As the National Academies report *Rising Above the Gathering Storm* concluded, our innovation must be fed in large part by strong investment in research and development at the frontiers of engineering, which is, for the most part, the land of the young. Indeed, those frontiers are being wonderfully explored by the participants in NAE's Frontiers of Engineering programs.

There are two obvious engineering frontiers. One is the so-called bio-nano-info frontier, the domain of things that are becoming smaller and smaller, faster and faster, and more and more complex, things that are based on or done by biological entities. On this frontier, science and engineering are not just interdependent; they have become largely one and the same.

The other frontier is the macro-systems frontier, the domain of things that are becoming larger and larger and more and more complex. This is where advances in energy, environment, manufacturing, logistics, and communications are conceived and realized. The macro-systems frontier has obvious societal importance. To prepare for or work in this domain, engineers and applied scientists must interact with people in the social sciences, management, law, humanities, and medicine. NAE has great potential to encourage these interactions and help build these interfaces.

I suspect that thinkers and doers in industry and academia will soon build strong bridges between the two frontiers, as nanoscale science, synthetic biology, biomimetics, and so forth are applied to the needs of real people on a grand scale. Obvious examples include new ways of designing and manufacturing materials that leave much smaller environmental footprints, the development of personalized and predictive health care, and the creation of means of generating substantial amounts of energy through economically sensible biobased fuels. Small-scale science and engineering will drive our approaches to our largest and most important systems.

Conclusion

I again congratulate each of you on your election to NAE. I hope that you recognize your membership as an opportunity to serve your nation and the world by helping provide well informed, objective, independent advice on crucial matters to our nation that involve technology.

Developing and transmitting such advice is an important way of exercising engineering leadership. You come to this task at a moment in history when there is an urgent need to sustain and enhance the technological welfare of the nation, so that we can both compete in the global knowledge-based economy and maintain our prosperity. You also come to this task at a time when the frontiers of engineering, at both the small and large scale, are not only enormously exciting but also critically important to meeting the great challenges of energy, environment, productivity, health care, food, water, and security.

Source: "NAE's Mission to Provide Leadership." The Bridge: Linking Engineering and Society (Winter 2007). Eds. George Bugliarello & Carol R. Arenberg. Vol 37, No 4; pp 42-46. National Academy of Engineering. Washington, DC. https://www.nae.edu/File.aspx?id=7414

The Challenges Ahead

Charles M. Vest Presidential Address at the 2008 NAE Annual Conference

October 5, 2008

Part of the core mission of the NAE is to *promote the technological welfare of the nation.* Engineering is critical to meeting the fundamental challenges facing the U.S. economy, environment, health, security, and way of life in the 21st century. Although industries are well aware of the centrality of engineering to the production of competitive products and the delivery of services in the world marketplace, governments at both the federal and state levels are struggling to understand and incorporate scientific and technological knowledge into policies that are, literally, matters of life and death.

In his *New York Times* column last Sunday, Tom Friedman, who will be with us tomorrow, made this point clearly in a commentary on the Wall Street bailout and the need for a green future. He wrote, "…we don't just need a bailout. We need a buildup. We need to get back to making stuff based on real engineering not just financial engineering."

Letter to the New President

In case you haven't noticed, we in the United States are in the midst of a presidential election, which, blissfully, will soon be over. Our nation will have a new president who will set about the tasks of assembling an administration, refining his vision, establishing goals and strategies, and preparing a budget.

But these are no ordinary times. We are facing tectonic shifts in the world order: global economies are increasingly intertwined; levels of education and knowledge development are rising everywhere; U.S. popularity around the world is at an all-time low; our addiction to oil has created an unstable situation in which we send about $400 billion each year to other countries to purchase it; we are awakening to the need to mitigate global climate disruption and the need to adapt to it; huge swaths of public primary and secondary education are disaster zones, especially in science and math; North America, Europe, and Asia now each fund about one-third of the world's R&D (i.e. the United States is no longer the biggest investor); the complexity of our financial system has grown beyond our ability to fully understand it, and, coupled with some of our baser human tendencies, we are close to the brink of economic collapse; we face insidious security threats that are entirely unlike those posed by nation states

"...globalization and our other major challenges bring with them extraordinary opportunities—opportunities for human advancement and opportunities for business and commerce."

for most of our lifetimes; and an inadequate supply of water is an imminent threat not only in the developing world, but here at home. Much more could be added to this list, but the point is that the 21st century is very different from the 20th century, and it brings with it enormous challenges—challenges on a huge, frequently global, scale.

During my first year as NAE president, I have had the opportunity to travel a lot, think about these issues, consult with leaders of various sectors and countries, be inspired by the amazing young participants in our Frontiers of Engineering programs, sit on interesting committees, and learn from my colleagues here at the National Academies. From these experiences, I have arrived at a few conclusions. First, globalization and our other major challenges bring with them extraordinary opportunities—opportunities for human advancement and opportunities for business and commerce. Second, science and engineering are at the core of the solution to most of our challenges and problems. Third, our political process and popular worldview are largely oblivious to the centrality of science and engineering in these matters.

In this context, many in our engineering, science, and medical communities are advising, or attempting to advise, whatever new administration will be installed in January. Various organizations and publications are presenting reports or letters to the next president, and the National Academies is no exception. My colleagues, Ralph Cicerone of the National Academy of Sciences and Harvey Fineberg of the Institute of Medicine, and I sent correspondence to the two presidential candidates, and a National Research Council committee was convened to produce a document identifying the most critical posts to which the next administration must appoint leaders with science and engineering backgrounds.

In this same spirit, a magazine asked me to draft a brief letter ostensibly to our new president. Here it is:

Dear Mr. President:

Your ability to govern effectively and provide world leadership will depend profoundly on advancing and utilizing the knowledge and tools of science, engineering, and medicine.

In the 20th century, U.S. science, engineering, and medicine nearly doubled our life span, protected our nation's security, fueled most of our economic growth, sent us to the moon, fed the planet, brought world events into our living rooms, gave us freedom of travel by air, sea, and land, established instant worldwide communications, enabled ubiquitous new forms of art and entertainment, and uncovered the workings of our natural world. It was a century of speed, power, and new horizons. We have come to take all this for granted.

The 21st century will be very different. And nothing can be taken for granted. To grasp the great opportunities of our times and to meet our challenges—from economic competition to energy, from healthcare to education, from security to infrastructure—federal policy and action must be informed and enabled by a vibrant science and engineering enterprise. Indeed our national comparative advantage is a strong S&T base coupled to a free market economy and a diverse, democratic society. We will soon feel the full force of global competition. Jobs will follow innovation wherever in the world it is found, and innovation will follow basic research wherever it is conducted. All our children must be inspired and educated for productive, well-paying jobs in this knowledge economy.

The bipartisan America COMPETES Act was passed and signed into law in August 2007, but has not been funded. It would jump-start improvement in K-12 science and math education, strengthen and sustain long-term basic research, make the U.S. the best place in the world to study and do research, and help ensure that we remain the most innovative nation on the planet. Its cost is about 0.14 percent of the Wall Street bailout, 0.8 percent of this year's economic stimulus, or 1.8 percent of annual farm subsidies.

American science and higher education are admired throughout the world and are wellsprings of badly needed good will toward our nation. By fully exploiting our capacity in science, technology, and medicine, you can project U.S. leadership abroad, enhance the quality of life at home, and better prepare us for the uncertain challenges of a rapidly changing world.

Mr. President, the federal government must invest in our future through education, research, and innovation. I therefore believe you should take six immediate actions:

- *Use your bully pulpit constantly to establish a public vision of an America that will lead and prosper in the 21st century through knowledge and innovation.*
- *Appoint an outstanding science and technology advisor prior to your inauguration and include him or her at the highest tables of counsel and decision-making in a manner parallel to the national security advisor.*
- *Make full finding of the bipartisan America COMPETES Act a non-negotiable first-term priority.*
- *Establish a bold national initiative engaging the private sector, academia, and government to meet our energy challenge and mitigate the advance of global climate disruption.*
- *Restore strong DOD basic research budgets and grow the NIH budget in excess of inflation.*
- *Work with Congress to eliminate academic earmarking.*

My colleagues in industry, academia, and government stand ready to support your new administration with fact-based advice and to provide the knowledge and innovation required for U.S. prosperity and improved life around the world.

Respectfully,

Charles M. Vest

I hope this message is consistent with the views of most NAE members. It certainly is reflective of the National Academies report, *Rising Above the Gathering Storm: Energizing and Employing America for a Brighter Economic Future,* which was drafted by a committee ably led by Norm Augustine and is the primary basis of the America COMPETES legislation. The letter also draws in large measure on the message our three academy presidents sent to the candidates. It succinctly lays out an agenda that I hope you can support.

Grand Challenges for Engineering

Niccolo Machiavelli said many things, most of which I won't repeat today, because you might fear that just one year in Washington has already corrupted my psyche and distorted my values. But there is one very important thing that Machiavelli famously

said, "Make no small plans because they have no power to stir the soul." This is very good advice for us as we think about the relationship between engineering and society, promote a broad public understanding of what we do and why it is important, and especially as we seek to inspire young men and women to become engineers.

Whether or not Machiavelli inspired him, during Bill Wulf's presidency, NAE formed a committee of extraordinarily innovative, successful, and diverse engineers, scientists, entrepreneurs, and one medical doctor. Former U.S. defense secretary and NAE member Bill Perry chaired the committee, and it was ably organized by Randy Atkins. The committee's charge was to develop a list of a modest number of grand challenges for engineering. These were not to be outrageously distant challenges, but challenges of great importance that the committee believed could actually be met in the next few decades if we set our minds and resources to doing so. The committee also established an interactive website that enabled a wide public to suggest challenges and join in the project.

Ultimately the committee established 14 grand challenges:

1. Make solar energy economical.
2. Provide energy from fusion.
3. Develop carbon-sequestration methods.
4. Manage the nitrogen cycle.
5. Provide access to clean water.
6. Restore and improve urban infrastructure.
7. Advance health informatics.
8. Engineer better medicines.
9. Reverse-engineer the brain.
10. Prevent nuclear terror.
11. Secure cyberspace.
12. Enhance virtual reality.
13. Advance personalized learning.
14. Engineer the tools of scientific discovery.

These challenges basically fit into three categories: (1) energy, sustainability, and global climate change; (2) medicine, health informatics and healthcare delivery systems; and (3) reducing our vulnerability to natural and human threats and advancing the human spirit and capabilities. Think about these challenges. Meeting some of them is imperative for human survival. Meeting others will make us more secure against natural and human threats. Meeting any of them will improve quality of life.

The Grand Challenges for Engineering were announced last February, and in the following day or two only a few small paragraphs appeared in mainstream U.S. print media. But in Europe and Asia, they received very substantial coverage. This is an all-too-familiar syndrome—complacency at home and enthusiasm elsewhere in the world. NAE then posted the Grand Challenges on the interactive website where visitors can help prioritize them. So far, the website has had about 170,000 visitors from people in 40 countries. More recently, the challenges were published by the NAE in a booklet with an essay on each.

I'm pleased to report that this project has created a good bit of stir in the blogosphere, and a brief video about the project can be found on YouTube as well as on our own website. This is good news, because it means we are reaching and engaging young people. The challenges will also play a central role in a documentary movie, *ImagineIt*. This robust, fast-paced film deals with a new generation, global challenges, and the power of imagination.

Several engineering schools and departments have informed us that they have mounted

project courses based on the Grand Challenges for Engineering. Next March, Duke University, in partnership with the University of Southern California and Olin College, will hold a summit of leading engineering, science, humanities, and social science scholars from across the nation to articulate the challenges and opportunities of the science, technology, and policy related to each NAE Grand Challenge and to propose solutions. They also intend to stimulate conversations on the importance of engineering and science in maintaining and enhancing our quality of life.

At our symposium tomorrow afternoon, we will bring together the themes of political realities of 2008 with the far-reaching Grand Challenges through a conversation among some of the committee members with a distinguished group of journalists and representatives of the McCain and Obama campaigns. Committee members Lord Alec Broers, Bernadine Healey, and Ray Kurzweil will be joined by author and *New York Times* columnist Tom Friedman and Daniel Sieberg of CBS News. Former Hewlett-Packard CEO Carly Fiorina will represent the McCain campaign, and former U.S. Undersecretary of Defense Paul Kaminski will represent the Obama campaign. Aaron Brown, former ABC and CNN news anchor, will moderate the conversation and audience participation. It should be a fascinating symposium, and we hope that all of you will join us.

Source: "The Challenges Ahead." The Bridge: Linking Engineering and Society (Winter 2008). Eds. George Bugliarello & Carol R. Arenberg. Vol 38, No 4; pp 55-58. National Academy of Engineering. Washington, DC. https://www.nae.edu/File.aspx?id=13306

Morgantown native Emily Calandrelli meeting Chuck Vest in 2010 when he came to WVU for a talk by Norm Augustine. Photo courtesy of Emily Calandrelli.

"In my household, one famed West Virginian was talked about more than the others. As I grew an interest in math and science, my dad starting telling me of a lesser known, but no less successful person from Morgantown, WV. As if he were his own best friend, my dad would brag about the accomplishments of Charles Vest – Morgantown High School and West Virginia University alumna who went on to become the President of MIT. We had the same academic foundation, and so he became a living symbol of what someone from my own hometown who went to WVU could accomplish."

—Emily Calandrelli

(See Emily's full tribute to Chuck Vest in Appendix B)

A Time for Fundamental Change

Charles M. Vest Presidential Address at the 2009 NAE Annual Conference

October 4, 2009

In his *New York Times* column one year ago, Tom Friedman contrasted the Wall Street bailout with the need for a green future. He wrote, "…we don't just need a bailout. We need a buildup. We need to get back to making stuff based on real engineering not just financial engineering." That was one year ago.

Two weeks ago, he wrote about the visionary work of one of our fine Silicon Valley companies that produces photovoltaic solar cells. A great story, but every manufacturing job associated with the company is in another country, specifically Germany. Friedman then noted that while many in the United States continue to treat renewable energy largely as a fairy tale, the renewable energy industry in Germany, with more than *50,000 new jobs, is now second only to its automobile industry.*

What is this about? It is a harbinger of a nation that has for too long ignored many of the greatest challenges of our age. It is about a nation in which far too many citizens and leaders assume that because we have been king of the mountain throughout their lives, the future will be no different. It is about the most innovative nation on the planet failing to harness that innovation in some of the most important directions. It is about a nation that for decades has given up on providing a world-class education to its primary and secondary students and now is tearing into the core of its great public system of higher education. It is about a nation that properly and generously shows the rest of the world how to build the foundations of strong economies while it stubbornly forgets its own lessons at home. It is about a nation increasingly unable to find a proper balance between short-term gain and long-term vitality. It is about a body politic that thinks globalization is an evil out on the horizon, when in fact it has been the reality of our businesses and industries for decades and must be shaped as a source of economic strength. It is about a nation in which someone seems to arise every morning and ask, "What new thing can we do today to become even less hospitable to people from other countries who want to visit, study, or become part of our society?"

I have asked myself if I could really stand here this morning and go through this litany yet again. After all, our National Academies report *Rising Above the Gathering Storm: Energizing and Employing America for a Brighter*

"As a nation we must refocus on the real economy, and that will require a re-energized innovation system to generate new knowledge and technology and move them successfully to the competitive world marketplace."

Economic Future presents the clearest summary of these issues and provides the strongest recommendations for changing course. The report has had some impact, but its findings were released in 2006, and we still have not seen broad, fundamental change.

The time really has come to slay the dragon of complacency. There is little slack left, and other nations are not biding their time. I really am worried. Indeed, I am frightened. But deep inside me there is still a spark of optimism, based in the first instance on something Winston Churchill once said, "You can always count on the Americans to do the right thing…after they have exhausted all the other possibilities."

I also have a sense of underlying optimism because this generation of young people is idealistic and is attracted to addressing the grand challenges of the 21st century. And we surely can make them aware that this is indisputably the most exciting era in engineering and science in human history.

So, how do we get back on track? The short answer is, we update the recommendations of *Rising Above the Gathering Storm* and implement them. But today I would like to explore three essential components of any reasonable strategy for moving forward: developing brainpower, unleashing innovation, and grappling with scale.

Developing Brainpower

Our age is both global and knowledge driven. As the world has become wealthier and generally better educated, science and engineering talent and knowledge are being distributed more broadly. North America, Europe, and Asia each accounts for roughly one-third of the world's R&D expenditures. China now leads the world in the number of young engineering professionals; India leads the world in the number of young professionals in finance and accounting; and the United States leads the world, by a small margin, in the number of young life-science professionals.

But coupling science and engineering gives us a misleading picture. The global trends in the engineering workforce are very different from those in the scientific workforce. In the early 1980s, China, Japan, and the United States each graduated about 75,000 bachelors-level engineers per year. By 2002, the most recent year for which accurate data are available, first degrees in engineering in the United States had dropped to about 60,000; in Japan they had grown to more than 100,000 graduates per year; and China had leaped to about 250,000 first engineering degrees per year. Yes, there is a wide variance in the nature and quality of engineering education, but the trend is very important.

You might say, "Of course China should have many more engineers than we do. After all, their population is nearly 1.5 billion, and they are rapidly industrializing." I agree, so let's look at a more important indicator, the fraction of college graduates who earn degrees in engineering. Broadly across Asia, Europe, and the United States the fraction of graduates with first degrees in the natural sciences is approximately 12 percent in each region. However, the fraction of graduates with first degrees in engineering is 20 percent across Asia, 12 percent across Europe, but only 4.5 percent in the United States.

I believe that the low fraction of our students majoring in engineering is something we really need to worry about. The fact is that we have been filling in the corresponding gap in our engineering workforce for many years by importing talent from other countries. Well more than half of the engineering and science Ph.D. students in U.S. universities come from other countries, and these immigrants have assumed major leadership in our universities and in our entrepreneurial industries.

We are grateful and should celebrate the leadership and contributions of these talented immigrants and the traditional openness of our country, campuses, and industries. But we cannot necessarily count so heavily on

them going forward. Many more are beginning to return home because of perceived higher speed of professional growth and better opportunities to start their own businesses.

We also need to make our borders more welcoming and especially to implement the *Gathering Storm* recommendation to increase the number of H1-B visas issued each year, and we should offer H1-B visas to students who earn doctoral degrees in STEM fields.

But our fundamental task must be to increase the number of U.S. citizens entering these fields. This requires two things: inspiration and improved education. We must inspire the next generation to contribute to a better world and a stronger economy through engineering and science; and we must somehow become serious about improving our public K-12 education.

There are productive roles here for the National Academy of Engineering. NAE's Grand Challenges for Engineering is proving to be an effective organizing framework for inspiring the next generation. And the Grand Challenges are a wonderful example of how seeds planted by the NAE can be leveraged through the passionate work of others. Several engineering deans and university presidents around the country have picked up the agenda of inspiration and run with it. Next spring there will be six coordinated summits in different parts of the country that will bring students, faculty, and leaders of industry and government together to focus on two or three of the NAE Grand Challenges.

With the leadership of Dean Tom Katsouleas at Duke, Dean Yannis Yortsis at USC, and President Rick Miller at Olin College, there is a national movement to establish a program of Grand Challenge Scholars among engineering undergraduates to "foster undergraduate research, study, and experiential learning related to the National Academy of Engineering Grand Challenges for Engineering." In addition, there are undergraduate project courses, and even reorganizations of curricula around the country building on our Grand Challenges report.

Let me return to improving education. This is a very complicated issue, but I want to point out one shining example. *Rising Above the Gathering Storm* recommended bringing to national scale a program started several years ago in Dallas by businessman and philanthropist Peter O'Donnell that provides modest financial incentives to teachers to qualify to teach science and math at the AP level. The program also provides a modest payment of a few hundred dollars to students who pass AP subjects in math, science, and English. The results of this simple program have been simply amazing.

Following the release of *Gathering Storm*, while waiting for the federal government to consider setting up an AP program, a non-profit, private sector organization—the National Math and Science Initiative (NMSI)—was established with financial support from ExxonMobile, the Gates Foundation, and the Dell Foundation. During its first year, the NMSI AP program is in 67 schools in seven states; and 13,000 exams were taken by AP students in science, math, and English, an 80.1 percent increase over the previous year. There was also a 51 percent increase in the number of AP exams passed, which is more than nine times the national average. The percent increases among women and underrepresented groups was even higher. This program will expand in the coming years. NMSI's second component, UTEACH, now operating in universities in 14 states, aspires to meet the *Gathering Storm* goal of graduating 10,000 K-12 teachers appropriately educated in the disciplines they teach.

My point is that there are things that can be done. Individuals can make a difference. And the work of the NAE and the National Academies can be leveraged by private groups, as well as by the federal government.

Unleashing Innovation

The United States is facing an economic crisis unmatched in recent memory, and there is general consensus that this crisis was precipitated by building far too much of our economy on vaporous transactions that did not create real value. To emerge from this financial crisis and set a sound 21st century course, we must turn our attention to unleashing engineering innovation to create products and services that add actual value.

As a nation we must refocus on the real economy, and that will require a re-energized innovation system to generate new knowledge and technology and move them successfully to the competitive world marketplace. We must become more productive and efficient at the things we already do well, create new industries, and transform others. We need to address energy, environment, security, and health care delivery in order to sustain our economic stability and quality of life. Our innovation system itself must evolve to meet these large-scale challenges.

The American innovation system, as I think of it, is a loosely organized system that creates new knowledge and technology through research and educates young men and women to understand and create this new knowledge and technology and move it to market as new products, processes, and services.

This system, which has been an enormous success from any perspective, derives largely from the 1945 Vannevar Bush report, *Science—the Endless Frontier,* which established universities as the primary element of the nation's basic research infrastructure and recommended the establishment of a National Science Foundation. That report still accurately describes a large part of technological innovation in the United States, especially the chain that runs from universities through entrepreneurs and venture capitalists.

However, during the last 40 years, the core of the innovation system involving large corporations has changed substantially about every decade. In the 1970s, central corporate research laboratories dominated; in the 1980s, corporate R&D was transformed and absorbed into a new style of product development in response to the challenge of Japanese consumer manufacturing; in the 1990s, large companies acquired innovation by buying start-up companies often spun off from research universities; and now in the early 2000s, globally open innovation has begun to play a major role.

Several things suggest that we may see another shift in the U.S. innovation system:

1. The scientific basis of new technologies will increasingly come from the life sciences and information technology.
2. Macro-scale systems challenges, especially energy, will drive innovation in the coming decade.
3. Venture capital may now be too risk averse and may not fit some large-scale systems.
4. Globalization of R&D investments, education, and high-quality workforce will continue apace.
5. Economic growth may require a new enabling technology analogous to IT and the World Wide Web in the last century.
6. We will need transformative breakthroughs to address many global grand challenges, such as energy, healthcare, and security.

Perhaps our current innovation system will simply continue to evolve. More likely, it will be augmented or readjusted to tackle large-scale 21st century challenges. For example, a 2004 NAE study proposed that Discovery Innovation Institutes be located on the campuses of research-intensive universities. They would conduct engineering research and innovation on a large scale and would have direct linkages to industry and government to guide use-inspired research and more efficiently move new ideas, discoveries, and technologies into practice. Such institutes would be especially suitable to addressing complex, large-scale, long-lived challenges such as energy. Indeed, DOE recently proposed something similar.

In higher education there are many experiments underway to foster and enhance innovation capacity and new modes of thought. Olin College of Engineering, near Boston, has operated now for seven years with an untraditional, design-oriented curriculum and an organizational structure without the usual disciplines. Finland is constructing the entirely new Aalto University, which will combine technology, economics, and art and design. Singapore is establishing a new university in partnership with MIT that will be focused heavily on science, engineering, information systems, and architecture, with a special emphasis on the role of design, broadly defined.

In California, Singularity University is the working name of a joint effort by NASA, Google, and several leading thinkers, such as NAE member Ray Kurzweil, to cross-educate students from the emerging disciplines of nanotechnology, biotechnology, and information technology and prepare them to attack the great challenges of our times.

Another intriguing attempt to drive innovation to achieve large goals is the work of the X-Prize Foundation. In 1996, the $10 million Ansari X-Prize for the first nongovernmental group to achieve human space flight went to Burt Rutan, who in turn was financed by Paul Allen, both NAE members. The goal of the X-Prize Foundation is to spur innovation to solve other highly challenging and important societal problems by leveraging the financial and intellectual resources of contest entrants. The DARPA Grand Challenge Program has a similar structure.

Finally, there are many emerging Web-based platforms for developing and using the collective input of large numbers of people to forge new ideas, solve problems and, in a broad sense, innovate. For example, *Rosetta@home* is a website that enables thousands of people around the world to play a massive computer game whose real purpose is to use their collective brainpower to solve highly complex problems of protein folding and bimolecular design.

Grappling with Scale

Driven by relentless change, globalization, distributed intelligence, the new generation will undoubtedly reshape our innovation system, and it will be none too soon. I am optimistic that we can move forward on developing brainpower and unleashing engineering innovation, but it is less clear to me how we can adapt our industrial and innovation base to meet large-scale national goals. For example, how will we deploy a modern electrical transmission and distribution system capable of intelligent operation and adaptation to highly variable renewable energy sources? How will we reinvent our manufacturing base?

A primary historical lesson from the 20th century is that the answer is not central planning. Government-generated technology road maps or other grand detailed plans, in my view, are not the way to go. But neither is the anything-goes, political-interest generated collection of regulatory regimes that break the current electrical grid into a multiplicity of overly independent segments. Somehow

we must establish a common vision of the so-called Smart Grid and set common regulatory standards and common technology standards that can be met in various ways by regional entities and the private sector. This is another kind of social/technical grand challenge for our nation.

Finally, it is time for healthy but objective debate about how far we can move into a service economy. It is empirically evident, and possibly desirable, that the fraction of our workforce employed in the service sector, broadly defined, is approaching 70 percent. But can we truly prosper without some form of transformed manufacturing base?

Efficient, low-cost manufacturing is the essential element in the deployment of batteries, solar cells, and other green technologies. Is it really okay if the manufacturing jobs in emerging green industries are established in other countries to begin with, rather than following the past trend of starting here and moving overseas as the industry matures and margins become thin? Many thinkers, including a number of NAE members, believe that we must find a new manufacturing paradigm, perhaps based on emerging advances in fields like robotics and biological synthesis of materials and devices, where we might establish a lead. In any event, these are fundamentally important questions about the innovation system that I hope we in the NAE can help address.

Source: "A Time for Fundamental Change." The Bridge: Linking Engineering and Society (Winter 2009). Eds. George Bugliarello & Carol R. Arenberg. Vol 39, No 4; pp 53-57. National Academy of Engineering. Washington, DC. https://www.nae.edu/File.aspx?id=17673

Technology and the Future of U.S. Competitiveness: Nightmares and Dreams

Charles M. Vest Presidential Address at the 2010 NAE Annual Conference

October 3, 2010

In 2005, the National Academies responded to a call from a bipartisan group of senators and representatives to recommend the top 10 actions that federal policymakers could take to enhance the science and technology enterprise so that the United States can successfully compete, prosper, and be secure in the global community of the 21st century. They also asked for a strategy, with several concrete steps, for implementing these actions.

Our response was *Rising Above the Gathering Storm: Energizing and Employing America for a Brighter Economic Future,* a report by a committee of 21 distinguished leaders experienced in industry, academia, philanthropy, and government. The committee was chaired, with remarkable effectiveness, by Norman Augustine.

Gathering Storm stimulated a great deal of conversation in Washington and throughout the country. Together with work by the Council on Competitiveness, *Gathering Storm* led directly to passage of the America COMPETES Act of 2007, which authorizes implementation of most of our recommendations. The act was passed with remarkably large bipartisan votes and was signed by President Bush.

Major components of the research budget we recommended have been funded during both the Bush and Obama administrations, but this funding is "metastable" at best. It was added to once by a supplemental appropriation and is currently funded largely through the FY 2010 Stimulus Bill.

ARPA-E, a venturesome new energy research office, has been established as recommended by our committee and is funding a plethora of exciting, high-risk, high-benefit R&D in small companies and universities. Unfortunately, our highest priority recommendations, the ones that deal with K-12 science, technology, engineering, and math (STEM) education and the preparation of a 21st century teacher corps, have not yet been substantively addressed.

Today we face metastable research funding, insufficient action in K-12 education, and the expiration of the COMPETES Act at the end of this year. For these reasons, my colleagues, NAS President Ralph Cicerone, IOM President Harvey Fineberg, and I asked Norm Augustine and the available members of the original committee to saddle up again, scan the economic and technological horizons, and see how our nation's competitive position has

"What happened to the charge-ahead spirit that led to the success of our 'moon shot' challenge? Today…we have a lot less public passion for engineering dreams into reality… It is time to change the national conversation and the national agenda, because dreams need doing. Nightmares don't! So, what will it be, nightmare or dream? It is our choice to make."

changed in the five years since their report was issued.

On September 23, 2010, we released their unanimously approved report, *Rising Above the Gathering Storm Revisited: Rapidly Approaching Category 5*. The subtitle, *Rapidly Approaching Category 5,* says it all. The committee's overall conclusion is that "in spite of the efforts of both those in government and the private sector, the outlook for America to compete for quality jobs has further deteriorated over the past five years."

The members of the committee continue to believe that the critical underpinnings of a successful nation in today's global context are encapsulated in their recommendations, which are divided into four groups:

1. Increase America's talent pool by vastly improving K-12 science and mathematics education.
2. Sustain and strengthen the nation's traditional commitment to long-term basic research.
3. Make the United States the most attractive setting in which to study and perform research so that we can develop, recruit, and retain the best and brightest students, scientists, and engineers from the United States and throughout the world.
4. Ensure that the United States is the premier place in the world to innovate, invest in downstream activities such as manufacturing and marketing, and create high-paying jobs based on innovation.

So why did they conclude that our situation has deteriorated? I can only scratch the surface here, but let's start with the fact that we in the United States have always considered ourselves to be *Number One*. But here is a little dose of reality about where we actually rank today:

- #6 in global innovation-based competitiveness, but #40 in rate of change over the last decade (ITIF, 2009)
- #11 among OECD countries in the fraction of 25-34 year olds who have graduated from high school (the older U.S. workforce ranks first among OECD populations of the same age) (OECD, 2009a, Chart A1.2)
- #16 in college completion rate and #20 in high school completion rate (OECD, 2009a, Chart A3.1)
- #22 in density of broadband Internet penetration (Dutta and Mia, 2010)
- #24 among 30 wealthy countries in life expectancy at birth (OECD, 2009b)
- #27 among developed nations in the proportion of college students receiving undergraduate degrees in science or engineering (OECD, 2009b, Table A3.5)
- #48 in quality of K-12 math and science education (World Economic Forum, 2009)
- #72 in density of mobile telephony subscriptions (Dutta and Mia, 2010)

This is not a pretty picture, and it cannot be wished away. As Bill Gates has said, "When I compare our high schools to what I see when I'm traveling abroad, I'm terrified for our workforce of tomorrow."

Successful entrepreneur Larry Bock says, "I find myself hiring talent for my companies abroad, not because I want to but because I can't find qualified engineers and scientists in America." By the way, Larry has taken the initiative by founding and driving the USA Science and Engineering Festival, a nationwide festival that will culminate in an expo on the National Mall here in Washington. NAE will have a great exhibit designed and implemented in partnership with Disney/Pixar to attract and inspire young people.

At our NAE Forum last year, NAE member and former DuPont CEO Chad Holliday said "[Other nations] have taken this recession [as an opportunity], not to talk about it, not to debate it, but to actually take steps … We must do exactly the same thing."

To further drive the point home, I quote China's premier, Wen Jiabao, "The history of modernization is in essence a history of scientific and technological progress. Scientific discovery and technological inventions have brought about new civilizations, modern industries, and the rise and fall of nations … I firmly believe that science is the ultimate revolution."

- Gulp.

Fact-based pessimism is in the air, and a national nightmare could be unfolding. But this does not have to happen. Even though it is the 11th hour, this nightmare need not materialize. Indeed I do not believe it will. But we must get started now on a strategic agenda for the long haul.

The *Category 5* committee believes that implementing its recommendations is an essential foundation for such a national strategy. It is by no means the entire foundation, but it is the core of that foundation.

Three Pushback Questions

When I have engaged in discussions about *Rapidly Approaching Category 5,* or about *Rising Above the Gathering Storm,* or for that matter in any discussion about engineering and the future, three questions almost always arise:

1. Why should we invest in research when our discoveries and inventions will inevitably be snapped up and commercialized in other countries?

2. Why do we need more engineers or scientists when people in other parts of the world can do their work for a fraction of their salary or wage?

3. How can you request more federal expenditures for research and education in this time of financial hardship and growing deficits?

These indeed are vexing issues, because one can find a lot of data that support—or seem to support—these positions. The pool of talented, well educated, or well trained workers in other countries, especially in Asia, is growing at a dramatic rate. And the salaries and wages for professionals and skilled workers in China, India, Vietnam and elsewhere is much lower than in the United States. We cannot control that. It is a direct result of rapid economic growth, supply and demand, market forces, stage of development, and also of history and culture.

These are daunting challenges for us and for the generation of Americans to follow. But inevitable? I can't see an inevitable devastating result here. Cause for profound worry? Absolutely yes. But I do not accept inevitability. Other countries cannot impose inevitability on us. It could only result from a loss of will or lack of logical response in our own country.

We all look back with great amusement at the prediction commonly attributed to patent commissioner Charles H. Duell in 1899, that "Everything that can be invented has been invented." Hopefully our grandchildren will look back someday and chuckle about those who at our turn of the century said, "Everything that can be invented in the United States and create domestic jobs has been. It's over."

America and Japan: Lessons Learned?

Perhaps we should pause and look back just 25 years and recall that in the 1980s, many serious people were convinced that Japan would dominate the world economy and that America would be crushed. That did not happen, and part of the reason it did not happen holds an important lesson for us today.

At the time, Japan had some major advantages. Its postwar generation worked incredibly hard in a very disciplined way. It had the advantages of building Greenfield factories, and–yes indeed–it had comparatively low labor costs. Its markets were either closed to us or were difficult for American companies to penetrate. It developed excellent engineering talent with a drive to excel, a deep attention to detail, and a respect for manufacturing. Japanese engineers set and accomplished bold goals for precision, performance, and miniaturization of consumer products.

The deep paranoia in the United States was based on a singular vision. Japanese students and visitors to the United States would take advantage of our open society by learning our technology and copying our innovations. They would then commercialize them and beat us economically—steal our technological crown jewels and run us over with them in the marketplace.

But what really happened? I contend that, in the end, the most important transfer of knowledge was not U.S. technology going to Japan but Japanese knowledge of manufacturing processes and quality transferred to the United States.

It was a painful period for us, but our consumer-manufacturing sector was forced to respond, and it transformed itself. This transformation was hard, and it is still going on, but in the end, because of our own actions, the Apocalypse never happened. Today, Japan is indeed a prosperous nation, and the quality of life of its people has increased dramatically. Despite its subsequent economic stagnation, it is still the second or third largest economy in the world.

So nothing was inevitable. But U.S. companies had to understand the changing reality and adjust to it by transforming themselves. They had to rebalance their competition and cooperation with Japan. We competed fiercely, and by accepted standards the Japanese were not always fair competitors. But there was an odd sort of cooperation as we learned from them how to produce high-quality products with previously undreamed of specifications, throughputs, and cycle times.

By facing reality and acting, the United States was able to persevere, and indeed entered an unprecedented era of economic growth and wealth generation as our entrepreneurial spirit exploded and our past investments in basic research led to vast new arrays of products and services. Among other things, we created the IT industry and launched the biotechnology industry.

Unfortunately, we lost that edge when we became overzealous about technology-based products that served very little real purpose. Market forces sorted that out, and the "tech bubble" burst, but we were left with some very important and, indeed, transformational companies and tools, *Google* being the prime example.

Responding to Category 5

In the last few years, a very different wave of economic damage has hit us. In my opinion it had two fundamental causes. First, markets were entirely distorted as unfathomable amounts of capital came under the control of people and organizations whose work added little if any actual value to the economy. We forgot basic things, such as that the purpose of houses is to provide shelter and a decent quality of life for families and individuals and that the purpose of banks is to safeguard people's money and provide loans at reasonable rates to individuals and businesses for legitimate purposes. We also forgot that the very sophisticated computational tools and quantitative models we have produced for complex tasks, such as evaluating financial risk, can only be applied effectively by people who have an understanding of how they actually work and of the assumptions on which they are based.

On top of all of this, there has been devastating indifference toward the miserably inadequate way a very large fraction of our children are educated, blindness toward how dramatically the world as a whole and our place in it have changed, and refusal to face up to the results of our addiction to fossil fuels.

This is a very bleak analysis, and I believe that we should be deeply worried. But my point in sharing my observations about the near-death experience of our manufacturing sector 25 years ago when Japan grew large on the world economic stage is that, once the truth sank in, we took the painful steps required to get back in the game. We analyzed, repositioned, persevered, and emerged stronger. We did it. In that case, the "we" was U.S. industry.

But this time around, more is required than change within companies. This time around we need a public awakening, establishment of political will, resetting of priorities, sacrifice for the future, and an alliance of governments, businesses, and citizens. This time we need truth telling, sensible investment, a rebirth of civility, and a cessation by both political and corporate leaders of pandering to our baser instincts.

Engineering, education, science, and technology are clearly critical to what has to be done. After all, this is the Knowledge Age. The United States cannot prosper based on low wages, geographic isolation, or military might. We can prosper only based on brainpower—properly prepared and properly applied brainpower.

This brings me back to the three questions asked frequently in response to the *Gathering Storm* and *Category 5* reports.

1. Why should we invest in research, when our discoveries and inventions inevitably will be snapped up and commercialized in other countries?

My answer is neither new nor original, but I believe it is correct. Robert Solow's well known, Nobel-Prize earning research taught us that the most important driver of productivity is technical progress driven by investment in research and new knowledge. Taking a very long view, Paul Romer's analysis of economic growth in the United Kingdom and the United States over a period of two centuries shows that it was only possible because of the continual development and advancement of technology.

Where do new technology and new knowledge come from? They come from research. And where do the really transformative innovations come from? They come from long-time horizon research—fundamental research and use-inspired basic research. Federal investment in U.S. university-based research brought us the computer, the laser, the enabling technologies of the GPS system, numerically controlled machines, the Internet, the deployment of the World Wide Web, the genetic revolution, and most of modern medicine. There are virtually no jobs in the United States today that are not directly enabled by one or more of these research-based innovations.

If we do not invest vigorously in basic research, an economic downslide is assured. If we do invest vigorously in basic research, we have a chance. By being first out of the box and increasing the probability of transformational breakthroughs, we can be first to produce and first to market. If we look clearly and holistically at our innovation system, we should be able to carve out job-producing space, especially at the high end.

I will be the first to admit that there are no guarantees and that tax policy, health care, patent protection, and other major factors must also be addressed. But no research, no chance.

2. Why do we need more engineers or scientists when people in other parts of the world will do the work for a fraction of the salary or wage?

I for one am not ready to fold up the tent and leave the field of competition. Dare I point out that that salary and wage rates in every other category of employment also are lower outside the United States? So at heart, no matter how well informed or intentioned, this perspective reflects a *"can't do"* mentality.

A month or two ago, it was reported that new manufacturing jobs were beginning to emerge in the United States, but workers with appropriate technical and quantitative skills are not available to fill them. A basic finding of the study of economic development is that the larger the number of technologically trained and creative people who come in contact with each other, the higher the probability of innovation. Floyd Kvamme, a major venture capitalist in the development of Silicon Valley, defines venture capital as "the search for good engineers."

Across Asia today, 21 percent of university graduates are engineers. Across Europe, 12.5 percent of university graduates are engineers. In the United States the number is 4.5 percent. So why hasn't the United States already been steamrollered? The answer is clear. We have addressed the engineering gap by attracting remarkably talented people from around the world to study in the United States and have been fortunate that many have stayed and become leaders in industry, academia, and entrepreneurship.

Large numbers of such individuals still aspire to stay and contribute to the United States, but our visa policies are making that path increasingly difficult to follow. We must fix this *post haste*. Furthermore, this gravy train is slowing down. Larger numbers of engineers and entrepreneurs are returning to China, India, and elsewhere. Vivek Wadwha's surveys have shown that the primary reasons they are returning are that their professional careers or the companies they wish to found can be built much faster back in Asia or South Asia.

I believe that we need more U.S. engineers to create and lead the companies, products, services, and processes of the future. Despite the horrendous global headwinds that are rapidly approaching *Category 5*, there is still value in locating companies and manufacturing facilities where the smart and innovative engineers are.

3. How can you request more federal expenditure for research and education in this time of financial hardship and growing deficits?

Our colleague and peerless leader Norm Augustine answers this question based on his experience as an aeronautical engineer and business executive: "When it becomes necessary to reduce the weight of an airplane, you don't accomplish it by throwing off the engine."

Why do we react to this by laughing? It is because we immediately and nervously recognize that it is a clear truth and an accurate analogy. It is not flippant. It makes a valid and essential point.

Nightmare or Dream?

It is time we regained our optimism and our "can do" spirit so we can remain a great nation and meet the challenges of our time. The way to accomplish this is to reconnect what we do with what we dream. We need a country with more people dreaming about what's possible, where young people—no, all people—are inspired to imagine a better world and help make it a reality.

That was once the American way, but now we are wandering around seemingly aimlessly. What happened to the charge-ahead spirit that led to the success of our "moon shot" challenge? Today we carry far more computing power in our pockets than was on an entire Apollo spacecraft, but we have a lot less public passion for engineering dreams into reality. I don't mean mindless TV "reality," I mean real reality—improving the lives of real people and creating real jobs.

In the last century, big-thinking engineers brought us automobiles, airplanes, electrification, clean water, computers, refrigeration, radio, television, medical imaging, lasers, the Internet, and the Web. They transformed our world. Those engineers were mostly young, and they were empowered by education and funded by government, industry, and venture capital to create new technologies, hire people to produce them, and move them into the marketplace. That was the heart of the *real economy*.

Yes, some of those technologies also left a legacy of problems we now must deal with, such as cyber-crime, the specter of nuclear war, and a national addiction to fossil fuels. But if we can inspire, educate, and fund them, a new generation of engineers can be at the heart of solving these problems and of making dreams of a better world become the new reality.

Our *14 NAE Grand Challenges for Engineering* address energy, water, climate and sustainability; improving the delivery of healthcare; increasing security against both natural and human threats; and expanding human capabilities and joy. Some of these challenges must be met to sustain human life on Earth. All of them, if met, would improve the quality life on Earth.

Working to address the Grand Challenges should be made as appealing to people—especially young people—as excelling in sports or acting. The United States used to be full of people who believed in endless possibility, but pessimism is now holding us back. As my favorite philosopher, Pogo Possum, said, "We are surrounded by insurmountable opportunities."

I would like to challenge the Congress to reauthorize and fund the America COMPETES Act to help propel us back into 21st century innovation by training and rewarding competent and inspiring teachers; once again attracting the best and brightest minds from America and the world to study science, engineering, and mathematics; and supporting the fundamental research needed to power our economy by creating real value.

And I'd like to challenge all of us to stop shortchanging our children by failing to provide them with a world-class education that both inspires them to dream big dreams and empowers them make those dreams real. I am optimistic. Puzzles, problems, questions, challenges are what inspire young people. Want to see a kid crave science? Give her a cause. Let her know she can use science to change the world.

Dozens of universities across the United States now provide that opportunity through the NAE Grand Challenges Scholars Program, which will prepare students to be the generation that can tackle the big issues facing society. These scholars will build on a core of technical education, but will also be able to join forces with colleagues from humanities, management, political science, and law to meet these challenges of our time. Because of such initiatives, there are still Eureka! moments ahead of us. But we must draw young people in and excite and prepare them.

Re-defining who we see as heroes, perhaps with the help of the entertainment industry, is part of the answer. Americans need to watch, read, support, and demand what is important as well as what is entertaining. Artists can help open our minds, and athletes can show us the power of focused excellence, but then we'll need engineers to turn visions into reality. It is time to change the national conversation and the national agenda, because dreams need doing. Nightmares don't!

So, what will it be, nightmare or dream? It is our choice to make.

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Engineers: The Next Generation

Do We Need More? Who Will They Be? What Will They Do?

Charles M. Vest Presidential Address at the 2011 NAE Annual Conference

October 16, 2011

Do We Need More?

The distinguished National Academy volunteers who wrote the influential report *Rising Above the Gathering Storm* concluded that we need to increase the number of engineers graduating in this country. Not everyone agrees with this assessment, and I am frequently asked if we really need more engineers. I think the answer is "Yes," for at least four reasons:

1. U.S. industry, including the national security industry, is facing a wave of retirements in the next decade or two.
2. It is not crystal clear that we will be able to continue to fill the engineering gap with the best and brightest from other countries.
3. Many high-tech companies report that they cannot find qualified U.S. citizens to fill critically important engineering and technology jobs, including in manufacturing.
4. Most important of all, we need a new generation of brilliant engineers, researchers, and entrepreneurs to create a vibrant future, just as preceding generations did.

So, yes, I think we need more engineers and better engineers.

Thank goodness we live in a democracy where we have the personal freedom to choose what we study and how we plan to spend our lives. In the current unhappy economic times we have brought on ourselves, no doubt young people feel more constrained than I did at their age. But they still will have a lot of choice over time about what to make of themselves.

On the one hand, the last thing I would want is for the government or some other group to dictate fields of study or how many people we should have in each professional field. On the other hand, leaders in our society, including leaders in the private sector, which actually provides career opportunities, need to think clearly about current trends and what they imply about the future. This is necessary to provide broad guidance to our educational system, our culture, and our incentive systems.

Who Will They Be?

So what are some of the trends we might consider? First, we should think globally.

"Do I know what the next game-changing innovation will be? Of course not. But historical precedents lead me to be extremely optimistic that there will be one...if we invest in education and research, build a great environment for entrepreneurship, and put sound economic policies in place."

How do we stack up in the *education* of engineers? Thirty years ago the United States, Japan, and for that matter, China, all educated the same number of engineers each year, about 70,000. But over time, the number of U.S. students graduating with bachelor's degrees in engineering has declined, slowly but more or less continuously, to about 60,000.

In the meantime, Japan and even South Korea now exceed our engineering graduation rates. And of course, as you have heard many times, the number of first engineering degrees in China has reached the astounding number of almost 600,000! India apparently has followed similar trends, but data are very hard to find.

Yes, I know there is a huge range of quality in China's higher education system. But the best of their universities are getting pretty darn good in engineering and science, and we can safely assume that the overall quality trend is upward. I also know that China's population is more than 1.3 billion people, they are climbing the economic ladder rapidly, at least in the eastern part of their country, and they have a huge infrastructure to plan, design, and build. So of course, they need vastly more engineers than we do.

So it would be rational to ask what *percentage* of college and university graduates around the world are earning degrees in engineering and science. The answer is very interesting. Whether we look across Asia, or Europe, or the United States, roughly 10 to 13 percent of college and university students graduate with degrees in one of the natural sciences.

What about engineering? In Asia more that 21 percent of students who graduate are engineers. In Europe, just under 12 percent of recent graduates are engineers. In the United States, the number is only 4.5 percent. We are at the bottom of the list in this metric.

Does this make any difference? I think it does. I will come back to this, but for the moment, let's ask whether this small fraction of U.S. students graduating in engineering is a new phenomenon. Actually, it has been this small for almost 50 years.

While the total number of bachelor's degrees in *all* fields increased by 220 percent, from 500,000 in 1966 to 1.6 million today, the number of engineers graduated has increased at half that rate, from about 33,000 to just under 70,000. And the number of engineering graduates has pretty much remained stagnant since the mid-1980s—for the past three decades.

Who have we been educating, and who will we educate in the future? Now the plot thickens. Let's start with gender, because therein lies much of the reason for our small fraction of B.S. degrees in engineering.

Remember all that growth over the years in the number of bachelor's degrees? Women have been dominant in it. Their numbers grew by 350 percent during this period, from 200,000 in 1966 to 900,000 today. The number of men graduating increased by only one-third this rate. So today almost 60 percent of our university graduates are women.

But when we look at U.S. *engineering* graduates, we see a world-class flip-flop of this situation. (The flip-flop is so glaring it makes politicians look like amateurs.) Women in America today earn fewer than 20 percent of engineering degrees. That means only 1.3 percent of the women graduating from U.S. colleges and universities are engineers!

There are many historical and cultural reasons for this—some of which we understand and some of which we may not understand. But the fact remains that engineering attracts a very small share of the fastest growing segment of college students. This is a huge waste of talent. We can do something about this. No, we must do something about it!

Here is another piece to the puzzle. It turns out that when students arrive at universities for their freshman year, move into dorms, and begin their college adventure, almost 10 percent of them plan to study engineering. Wait a minute! I just said that only 4.5 percent of our graduates are engineers. Yes indeed, we lose half of them on their way through college. We lose 50 percent of the women, and we lose 50 percent of the men.

So there must be something about science and engineering education that drives students away. Right? Think again. Less than a third of the women students leave science before graduation. That is not good, but it's not as bad as the loss of 50 percent of the women who enter engineering. And the ranks of male scientists grow by 15 percent on the way through college. I can guess where the 15 percent growth comes from. It most likely includes many of the engineers we lost along the way. In other words, the problem is an engineering problem.

The bottom line is that half of engineering students leave the field during their university years. If we could stop that loss, we would instantly double our national output of engineers.

Why do they leave? Surely there are as many specific reasons as there are students, and surely the situation varies from school to school. But across the entire system, we are failing in some combination of inspiration, motivation, and learning.

That is one reason the National Academy of Engineering promotes and encourages innovation and change in the quality of experience and learning of our undergraduates. I think change is imperative, and I know that many people sitting in this room are effectively bringing about such change about in their institutions. But far more needs to be done. We have to consider the possibility that we are our own worst enemies.

I am worried that I am throwing too many numbers at you, not always a good idea in a speech. Sorry, but I have a few more. Because we have been looking in the rearview mirror and at the present situation, you might say, "So what? It's the future that counts. More women are coming into engineering now. This is an exciting time in technology, and engineers will be needed to address many of the grand challenges facing humankind in the years ahead. Maybe everything will be OK." Maybe. But I doubt it.

Looking ahead, one needs to think about the generation of Americans who are 18-23 years old. In 1985, 10 percent of these "college age" kids were Hispanic American. Today 17 percent are. Hispanics are on a very steep growth curve. College-age African Americans are also growing as a fraction of the population. The growth rate of young Asian Americans is higher still.

The point is that, taken together, our two largest racial minority groups comprise about one third of the college-age kids in our country, and that fraction is growing steadily. Nevertheless, they earn less than 13 percent of our engineering degrees. Let me repeat this. The fastest growing segment of our young population earns less than 13 percent of our engineering degrees. Projecting forward, this is a workforce train wreck in the making, and we must take action now to avoid it.

So why hasn't the United States already been steamrollered? The answer is clear. We have addressed the engineering gap by attracting remarkable talent from around the world to study in the United States, and we have been fortunate that many have stayed and become leaders in industry, academia, and entrepreneurship. Large numbers of these individuals still aspire to stay and contribute to the United States, but our visa policies are making their path increasingly difficult. We must fix this *post haste*.

Furthermore, the gravy train is slowing down. More and more engineers and entrepreneurs are returning to China, India, and elsewhere. Vivek Wadwha's surveys indicate that their primary reasons for returning are that their professional careers or the companies they wish to found can be built much faster back in China or India.

For many decades, we have followed a truly bizarre federal policy of (1) making it hard for brilliant, accomplished foreigners to enter the United States to work, and (2) pushing immigrants who have earned advanced degrees in our universities out of the United States. This is simply wrongheaded, and it has gotten worse since 9/11.

And by the way, it is not only wrongheaded, it is bipartisan. Leaders from Silicon Valley come to town saying, "For heaven's sake, staple a green card to every engineering and science graduate degree." No matter which party controls what, the politicians say, "We understand, and we are going to fix it, but it must be part of a comprehensive immigration bill." Then they return to partisan gridlock, being careful not to arrive at a comprehensive solution. The nation suffers the consequences.

To repeat, we are still considered a wonderful destination for engineers from around the world, but we go out of our way to make it difficult for them to get here or stay here. So, nonsensical immigration policy is *cause number two* for worrying about a possible workforce train wreck. On top of that, many recent immigrant engineers and entrepreneurs choose to return home or go to yet another country, part of a growing "brain circulation" around the globe. And, of course, many of our own young Americans are joining this great circulation. We need to press even harder to get this problem fixed.

But more important, we have to get serious about improving K-12 education in America. To that end, we must enlist everyone who understands the issue to work to change the conversation, and to get kids to understand that "Dreams need doing," and that, "Engineering is essential to our health, happiness, and safety." And we must help them to understand that most of the Grand Challenges facing humankind can only be solved if engineers are at the center of the effort.

Finally, we need to work creatively to improve engineering education across the country. We cannot rest on our laurels. Having been the best in the world for the last 50 years guarantees nothing as we move forward.

What Will They Do?

Yes, I am worried about the quantity and quality of the future engineering workforce, *but what will they do?* Suppose I had been asked this question when I graduated from engineering school in 1963. I probably would not have answered, "Why, they'll work in the IT industry." I wouldn't have given this answer because the IT industry did not exist. Yet a huge fraction of the engineers of my generation indeed ended up working in the IT industry.

The IT industry exists because engineers innovated. They figured out how to do new things, and some of those things, like IT, turned out to be game changers and major job creators. Indeed, the IT revolution created 22 million U.S. jobs in one decade.

Do I know what the next game-changing innovation will be? Of course not. But historical precedents lead me to be extremely optimistic that there will be one…if we invest in education and research, build a great environment for entrepreneurship, and put sound economic policies in place. We'd better do this, because we will increasingly need to be first out of the box and first to market with new products, processes, and services.

Come to think of it, if I had listened more carefully to the emerging language of

engineering in 1963, I would have had at least an inkling that something called IT might blossom and grow. I didn't have the necessary prescience. But if we listen to the language of engineering today, we will hear the same words I have heard throughout my career—terms like:

Force, Speed, Size, Tolerance, Modulus, Voltage, Temperature, Precision

This is the language of basic engineering, and it is as relevant today as it was when I started out.

But I also hear terms like:

Scale, Scope, State, Complexity, Integration, Architecture, Resilience, Evolution, Affordability, Social Context

This is the language of engineering systems. It is about how things are interconnected and interactive. And it is about the *integration* of what engineers know and can do with what social scientists, management experts, policy makers, citizens groups, lawyers, and politicians know and can do. Integration is essential for a vibrant future.

Last week, *New York Times* columnist David Brooks wrote this about Steve Jobs: "The roots of great innovation are never just in the technology itself. They are always in the wider historical context. They require new ways of seeing." Our universities need to prepare engineering students accordingly.

Let me tell you what else I hear. Increasingly, I hear terms like:

Cellular Circuitry, Adaptive Immunity, Reprogramming Bacteria, Synthetic Biology, Natural Adhesives, Bacteria-Laced Concrete, Integrated Cancer Research, Neuroprosthetics

This is the language of a new biological engineering, of the convergence of life sciences with engineering and physical science that is beginning to range far beyond medical applications. The life sciences, as well as biomimetics are new foundations for engineering. Biological engineering today is more or less where computers were in 1963.

And there is yet another strand of language I hear. I hope you hear it too, because we at the National Academy of Engineering are making a concerted effort to propagate it:

- Engineers are creative problem solvers.
- Engineers make a world of difference.
- Engineers help shape the future.
- Engineering is essential to our health, happiness, and safety.
- Engineers can meet the Grand Challenges of the 21st century.

This language is intended to change the public perception of engineering, especially among bright young people who aspire to prepare to make the world a better place by driving sustainability, helping advance the cause of better health, making the world more secure, and expanding humankind's capabilities to enable people to live more joyful, productive lives.

I am not worried about what engineers in this country will do in the future, and I do believe we will need more good engineers, because I believe they will continue to innovate, produce new industries, and drive economic and social vitality, just as they have for the last two centuries. To be more accurate, they will accomplish these things *if* we make the proper investment and, put in place appropriate policies and corporate and political leadership to build a vibrant future.

But one very important aspect of future jobs and engineering work in the United States is particularly puzzling. That is the future of manufacturing.

Twenty years ago, an MIT commission conducted a study that was published as an influential book, *Made in America*. The primary finding was that "To live well, a nation must produce well." Is this still true today, in 2011? The answer to this question has a major bearing on what engineers will be doing in the coming decades and where they will be doing it. It also has major ramifications for the nature of the U.S. economy and workforce. And it has a lot to do with jobs and education.

Although by some metrics, the United States is doing well in manufacturing right now, there are some very disturbing trends. For example, consider the manufacturing of solar photovoltaics. In the mid-1990s, the United States had almost half of the world's market share. Today, our share is about 5 percent. Well, this isn't a huge industry, so maybe we shouldn't care. However, this segment of green energy products and infrastructure may be a leading indicator, a harbinger of things to come. So maybe we should care.

Or maybe we shouldn't care because we are well on our way to becoming a service economy. Things change. In 1800, a full 90 percent of American workers lived and worked on farms. American farmers grew crops and raised animals to feed their families, and as time rolled on they fed their communities, and eventually they fed the nation and large parts of the world.

But their numbers have continually decreased, and today only about 2-3 percent of the U.S. workers are farmers. Why did this happen? It happened because farm productivity has increased astoundingly as scientific knowledge, sophisticated technology, and business organization were applied.

Then the industrial age came along, and most jobs displaced from farms reappeared in factories where workers produced increasingly numerous and complex products. They made things. By 1950, about 60 percent of U.S. workers were making physical goods in factories. As industrial productivity improved, factory jobs declined, and today less than one-third of the workforce is making physical things.

These were tectonic shifts. The old order has changed. As one telling example, in 1970 the Big Three automobile manufacturers employed more than 450,000 workers in the state of Michigan. Today, they employ fewer than 100,000.

We all know what happened. It's not just about increasing productivity. Our society became more complex and demanding. Then the IT revolution came along, and globalization spread operations all over the world.

Now the action and the jobs have moved to the service sector. Today, around 70 percent of U.S. jobs are in the service sector—ranging from flipping hamburgers to conducting sophisticated global operations using supercomputers, the Internet, and the World Wide Web.

So what happened to manufacturing? A lot of it moved offshore. In a typical scenario, a product may initially be manufactured here in the United States; then its production is moved to Korea or Taiwan; later it goes to China; and then it migrates to, say, Vietnam.

The common wisdom is that this happens because wages are much lower in those countries. But it is not that simple. Germany's manufacturing sector, for example, is booming and is responsible for 21 percent of its GDP. Yet the all-in wage rate for German factory workers is 40 percent *higher* than that in the United States.

It is not simply about "here or there." Today all large corporations are global entities. They have to be in today's economy. The end result is that we are generating enormous wealth in the United States, but the traditional manufacturing jobs, and increasingly, a big chunk of engineering functions, have gone to other countries.

Looked at from the perspective of the developing world, this is described as the "U Curve Theory." People in developing countries see the United States retaining many of the high-quality jobs in the front offices, R&D facilities, and design centers, while shipping low-wage manufacturing jobs to them. They see the big financial returns from these manufactured goods going back to the United States along with higher-paying marketing and sales jobs. There is some truth to this theory.

And remember in 1990 when Robert Reich famously asked, "Who is us?" He was asking whether the interests of U.S. companies and the interests of the U.S. economy were diverging. We still haven't answered his question. Today, in this bad economic climate, it is being asked again, including by protesters on Wall Street.

I think that we need some serious introspection about "Who is us?" and whose interests are being served. No matter the answer, globalization has been the dominant reality for several decades, and it is here to stay. Because the world is totally interconnected, both manufacturing and service functions are being distributed far and wide. As a consequence, corporate interests and national interests have become the Yin and Yang of global enterprise. Indeed, in today's world, nations must simultaneously compete to drive excellence and wealth and cooperate to improve efficiency and expand markets.

In my view, Robert Reich's question has no simple answer. But we should expect our leaders in both corporations and government to explicitly think through this issue and move toward a balance that favors our nation to the extent that is reasonable. Exactly how we define "reasonable" in this complex, interconnected, open, transforming world of competition and cooperation is not clear. But it must continually be on the minds of our leaders.

Above all, our leaders should lead by explaining the modern world better and investing the resources necessary for the next generation to succeed. But time is running out. I fear our politics has become a circus in the face of serious challenges and global transformations. It should not be our destiny to stand around and observe as a *New World* in the East moves on.

Our leaders must lead by implementing the agenda the National Academies laid out in *Rising Above the Gathering Storm.* That means investing big-time in long-term R&D. It means enabling us to attract the best and brightest from the United States and throughout the world to engineering and science. It means reinvigorating the environment for innovation and entrepreneurship. Above all, it means building an America that provides world-class education and training for all our young people.

Franklin D. Roosevelt once said, "We may not be able to prepare the future for our children, but we can at least prepare our children for the future."

Source: "Engineers: The Next Generation—Do we need more? Who will they be? What will they do?" The Bridge: Linking Engineering and Society (Winter 2011). Eds. Ronald M. Latanision & Carol R. Arenberg. Vol 41, No 4; pp 56-60. National Academy of Engineering. Washington, DC. https://www.nae.edu/File.aspx?id=55285

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What are We Waiting For? Sputnik? An Explanation of Today's World? New Ways of Working? National Strategy?

Charles M. Vest Presidential Address at the 2012 NAE Annual Conference

September 30, 2012

What Are We Waiting For?

I want to begin my remarks today by expressing my appreciation for the honor and privilege of serving as your president. It has been a very rewarding experience, and I hope that I have added some value to the NAE, and to the greater causes that we serve.

There is one thing that the outgoing leader of an important organization values above all else…that is that he or she will be succeeded by a new leader whom he or she deeply respects. Although I appropriately played no role whatsoever in the work of the Nominating Committee, I could not be more pleased than to have Dan Mote nominated to be our next president. We could not possibly do better.

But there are areas in which we could do better. For example, the embarrassing silliness of this political season has reinforced something that has bothered me for some time: For many years now, as a nation and as a body politic, we have been waiting. Waiting when we should have been acting and leading. What are we waiting for?

If I hear one more person say that our educational, scientific, and technological enterprises are waiting for another "Sputnik moment" I fear that I will react in some bizarre, illogical manner unbefitting this office.

But there are some things that I am waiting for, and I suspect that I am waiting for them in the good company of all or most of you. I am waiting for our political and corporate leaders to honestly explain today's world…clearly and continually in their public dialogue and through their strategies and actions.

I also think that far too much of our nation is waiting for new ways of working to arrive. We hear lots of rhetoric about how the nature of work will change, as if it relates to some unknown distant future. The fact is that it is happening now, and we need a broader recognition of this fact and policies and education that reflect it.

Finally, I am waiting for national strategies around the fundamental issues of our time. By "national strategy" I generally mean "rules of the road." One of the great lessons of the second half of the 20th century is that central

"…making value requires an integrated system of activities—including understanding customers, research, development, design, manufacturing, and services—necessary to deliver value to customers."

planning does not work. The private sector and especially entrepreneurial communities will beat central government planning every time. But, having said that, in my view many of the great national and global challenges we face today require the government and society to establish and sustain goals, directions, and policies that describe “rules of the road" according to which the private sector can find optimum solutions.

Waiting for Sputnik

When I was a high school student, America woke up one day and learned that the Soviet Union had placed a satellite named Sputnik into orbit about the earth. This injured our national pride, raised national security and geopolitical concerns, and led fairly quickly to a focus on the importance and quality of our science and mathematics education. It inspired many young people, including me, and in due course provided us with better teaching materials and with major increases in financial aid, from both corporations and government, for advanced studies in engineering and science, and new career opportunities. Like Pearl Harbor, it was a single, crystallizing moment of the kind to which our nation is good at responding.

But waiting for a new Sputnik moment in 2012 is folly. This generation already has its challenges, and they are far more fundamental and far more important than was a Soviet satellite. And most—perhaps all—of this generation’s challenges are *global*. They are global because our world is straining to support 7 billion people who share a single environment, finite natural resources, knowledge, economy and commerce, and, above all, a common humanity.

As you know, the NAE commissioned a committee of 18 superbly creative and innovative men and women to establish a set of Engineering Grand Challenges that, if met, would improve life on earth and that they believed could be accomplished if we set our minds and resources to them. These Grand Challenges fall into four large buckets: Sustainability, Security, Health, and Joy of Living. Mostly through the voluntary efforts of many leaders of higher education, these NAE Engineering Grand Challenges have led to numerous education and outreach programs and have entered the national dialog among business, government, and academia.

What I have observed through our Grand Challenges work, and through many campus visits and gatherings of entrepreneurs, is that this generation of young people is eager to engage. They aren’t waiting for Sputnik. So let’s all work together to provide them with the opportunities and resources to start meeting these Grand Challenges. Let’s stop dampening their well-informed enthusiasm and efforts by choking back funding of higher education, stalling research support, blocking immigration, and glorifying and rewarding careers that add no value.

Waiting for Leaders to Explain Our New World

Virtually everyone in this room is engaged in industry and commerce, in higher education, in research and development, or in national security. Each of us lives, works, and learns in a highly integrated, networked world.

Do you recognize this world in our political rhetoric? Do you hear our corporate leaders working explicitly and in a sustained manner to help our people understand this? Maybe you do, but I don’t.

The world has changed. We need to get on with it.

R&D investments by both the private and public sectors are increasingly spread around the globe. Currently they are approximately one-third in North America, one-third in Europe, and one-third in Asia. And the level of education is rising all around the world,

especially in the STEM disciplines. These new global distributions are good things. But we can't sit on our thumbs and watch much of the rest of the world approach and then surpass us in these important investments. In my view, our most important national comparative advantages are democracy, free enterprise, diversity, and excellence and inventiveness in higher education and research.

I think our leaders owe us more straight talk about the nature of today's world. In particular, we all must understand that, now and in the future, we must compete but also cooperate with others all over the world—other countries, other companies, other universities,…other colleagues. Cooperation and competition are the yin and yang of the modern world.

And sharing is the enabling mechanism—sharing of knowledge, sharing of talents, sharing of education. This is the new world of open innovation and of new ways of working.

During our 2011 NAE National Meeting, we held a forum on Manufacturing, Design, and Innovation. (See Appendix A for brief summaries of forum speakers' comments). Our colleague Rod Brooks was one of the panelists. Suggesting that we concentrate too much on the most sophisticated technologies and environments, he laid out a case for focusing on small, easily programmable robots to help humans perform fundamental manufacturing operations. Such devices could "democratize low-end manufacturing." Fast forward to last month, and note these words in Tom Friedman's August 26, 2012 *NYT* column describing Rod's newest venture, a company called Rethink Robotics:

> The Rethink design team includes Bruce Blumberg, the product manager of the Apple LaserWriter, as well as 75 other experts from Russia, Georgia, Venezuela, Egypt, Australia, India, Israel, Portugal, Sri Lanka, the United States and China.
>
> "It is all made in America," says Brooks, but by "the best talent" gathered "from around the world."

So here, in one package, are competition, cooperation, and new ways of working.

Waiting for New Ways of Working

Yet I keep reading about new ways of working that are going to happen in some distant future. In fact, they are happening now, and we need to be preparing more people for them.

A few decades ago, we talked about *brain drain*. This generally referred to the movement of highly talented young people, especially scientists and engineers, to the United States to study and subsequently contribute richly to our nation as faculty members, entrepreneurs, and business leaders. But "drain," of course has a negative connotation because to some extent America's gain was a loss to these individuals' home countries.

Today, especially for young people, we are more in an age of *brain circulation*, with students, entrepreneurs, and corporate personnel living and working in multiple countries during their careers.

But I believe we are rapidly entering the age of *brain integration*. By this I mean integrating people's minds with each other's and with computers. Here is a simple example of what I mean:

Think about the game of chess. A well-programmed computer can consistently defeat a human chess opponent. This was most famously demonstrated several years ago when IBM's Deep Blue defeated Gary Kasparov. But it turns out that a *team* of humans and a computer can be expected to beat any other human or any computer.

One of the most exciting examples of brain integration is by the website Foldit. Foldit is basically a computer game developed by

faculty at the University of Washington. It not only chains together many personal computers around the world, it also chains together many minds, because the thousands of people playing this game are in fact cooperating to solve complex protein-folding problems. Although, to the individual players, this is a new way of playing, in fact it is a new, cooperative way of working.

Douglas Thomas and John Seeley Brown explore the same concept of harnessing massively multiplayer online games for purposes of learning in the interesting book, *A New Culture of Learning*. But in this case, my use of the word "harnessing" shortchanges the concept of brain integration because the players and communities themselves develop the culture of learning; it is not a new way of doing traditional teaching and learning.

Finally I should note that developing such new ways of working and problem solving is the object of intense research at places such as the MIT Center for Collective Intelligence, which is devoted to answering a core research question: *How can people and computers be connected so that—collectively—they act more intelligently than any person, group, or computer has ever done before?*

Now let me turn briefly to the manufacturing sector. Our nation is perplexed about the future of manufacturing in the United States and about what manufacturing jobs have changed or will change. Too frequently, discussions about manufacturing revolve around a nostalgic view that the old jobs may return. In fact, we need to understand what the new jobs will be and how to prepare young people for them.

During the last several months, the NAE, with the guidance of an informal advisory committee headed by the visionary former General Motors executive Larry Burns, has helped us begin developing a new framework for thinking about the nexus of manufacturing, design, and innovation. We have held one major workshop of leaders from business, academia, and government, and are developing a fast-track set of research and analysis projects that we hope will be useful to the nation.

There is an exciting world out there involving additive manufacturing, biologically based manufacturing, design for sustainability, and advanced robotics. There is plenty of great and important R&D to be done in these fields, but the overall picture, and especially the issue of jobs, is much broader than just advances in these individual technologies.

Things are stirring. Our committee observed that, "While overall U.S. manufacturing employment has decreased by 5 million jobs since 1980, manufacturing employment requiring at least a college degree has *increased* by approximately 1 million jobs." That should make us sit up and pay attention.

The framework we are working toward is centered on *making value*. By this, we imply that it is not just about making things, nor is it just about creating services. It certainly is not just about making money in ways that add little value to customers or society, and it is not just about making anything confined solely to U.S. geographic boundaries.

In our developing framework, making value requires an integrated system of activities—including understanding customers, research, development, design, manufacturing, and services—necessary to deliver value to customers. Making value requires a holistic system of these activities that must be developed and optimized in the national interest.

If all of this sounds suspiciously like gobbledygook, just stop and think about what the iPhone and its progeny have done. For sure, they integrated innovation, design, and manufacturing. But they also created an entire new industrial ecosystem, especially the "app" industry. For sure, they made

money—but they also created opportunity for basement software developers, provided new platforms for business and for education, and either harnessed or unleashed creativity and innovation all over the world. They created and enabled a new ecosystem of people and activities. We believe this general framework of making value will extend far beyond just the IT device industry.

I hope that in the coming months our NAE work will meet three basic objectives:

1. Analyze existing best practices in holistic enterprises that make value;
2. Learn all that we can about the likely ecosystem that will support future work, including the skills, education, infrastructure, and government policies to enable and support new work; and
3. Determine the necessary and sufficient conditions to make the United States the ideal place to make value.

Waiting for National Strategy

I worry a lot about the seeming inability of the nation to set strategy, in the broad sense of establishing and sustaining "rules of the road." In fact, in the dark recesses of the night, I sometimes become afraid that this could be an Achilles' heel of democracy itself. I know that this is overly pessimistic, but let me give you an example of why I worry.

A few years ago, I visited a sprawling facility of one of our largest companies. It had invested huge amounts of money and engineering in several forms of alternate or renewable energy production—wind, solar, biomass, and the like. These had been carried to the large-scale demonstration level.

But the machines were just sitting there. When I asked what their plans were for bringing these huge devices to market, the answer was "We have no plans for commercialization. Our investment is ending because the government has set no energy policy and they have set no carbon policy. Until that happens, we will have no idea what the markets will be."

Government is not going to do the things that are required for us to have a vibrant economy, health, security, and quality of life.

Business is not going to address the things that are required for us to have a vibrant economy, health, security, and quality of life.

Academia is not going to address the things that are required for us to have a vibrant economy, health, security, and quality of life.

The fact is that we have to have all hands on deck. Each of these sectors must play its proper role and forge an alliance to meet today's challenges.

What we are missing is bold vision and leadership.

"Well," you might ask, "Don't you know that we have a big financial problem?"

"Don't you know that we have been fighting wars in the Middle East?"

"How can we summon bold vision and leadership in such a time?"

Here is a thought: 150 years ago, in the midst of the utter devastation of the American Civil War, our leaders conceived and passed the Morrill Act. The Morrill Act established our great system of land-grant universities to invest in the education of young people from all social strata. I would guess that most of us in this room were educated in land-grant universities.

And 150 years ago, in the midst of the utter devastation of the American Civil War, our leaders conceived and created the National Academy of Sciences because

they understood that "science and art" were fundamental to the development and expansion of our nation.

Until or unless such bold vision comes again, we must unleash our innovation system as best we can. This is a nonlinear, loosely organized system that still is the *best in the world*.

And we need to be at the forefront of other emerging models of innovation: inducement prizes; new, reorganized universities; virtual communities…

But we must remember that it all begins with education.

And something big is about to happen in education. We will explore this tomorrow in our Forum on the Future of Engineering Education.

Source: "What are We Waiting For? Sputnik? An Explanation of Today's World? New Ways of Working? National Strategy?" The Bridge: Linking Engineering and Society (Winter 2012). Eds. Ronald M. Latanision & Cameron H. Fletcher. Vol 42, No 4; pp 65-68. National Academy of Engineering. Washington, DC. https://www.nae.edu/File.aspx?id=67680

Selected Resources for More Information About Charles M. Vest

Charles M. Vest Memorial Booklet. A Celebration of Charles M. Vest's Life: The National Academy of Engineering and the Vest Family (February 20, 2014). NAE website offering links to a downloadable version of the Charles M. Vest Memorial Booklet and a video of the "Celebration of Charles M. Vest's Life." *https://www.nae.edu/26755.aspx*

Former MIT president Charles M. Vest dies at 72: As the Institute's leader from 1990 to 2004, he sparked a period of dynamism (December 13, 2013). Steve Bradt, MIT News Office. Article tracing Charles M. Vest's many accomplishments, from earning his BS degree in mechanical engineering from West Virginia University through his tenure as President of both the Massachusetts Institute of Technology and the National Academy of Engineering. *http://news.mit.edu/2013/former-mit-president-charles-m-vest-dies-at-72-1213*

Leading with Aesthetics: The Transformational Leadership of Charles M. Vest at MIT (2015). Mahesh Daas. This book presents a detailed case study of Charles Marstiller Vest's leadership as president of MIT (1990-2004), specifically examining its aesthetic dimensions and drawing from the fields of architecture, political science, organizational aesthetics, and organizational psychoanalysis. *https://rowman.com/ISBN/9781498502498/Leading-with-Aesthetics-The-Transformational-Leadership-of-Charles-M.-Vest-at-MIT#*

Pursuing the Endless Frontier: Essays on MIT and the Role of Research Universities (2005). Charles M. Vest. Massachusetts Institute of Technology (MIT) Press. A series of essays written by Charles M. Vest during his 14-year tenure as MIT President about the issues facing academic institutions in the 21st Century. *https://mitpress.mit.edu/books/pursuing-endless-frontier*

Engineering Systems: Meeting Human Needs in a Complex Technological World (2011). Olivier L. de de Weck, Daniel Roos, Christopher L. Magee, Charles M. Vest, Charles M. Cooper. MIT Press. A comprehensive examination of the field of engineering systems as its scale, scope, and complexity continue to increase, challenging engineers to address technical and social issues in an integrated way to meet human needs today and in the future. *http://www.goodreads.com/book/show/13006707-engineering-systems*

Rising Above the Gathering Storm: Energizing and Employing America for a Brighter Economic Future (2007). National Academy of Sciences, National Academy of Engineering, and Institute of Medicine of the National Academies. A report to federal policymakers outlining recommendations for enhancing the United States' scientific and technological endeavors to ensure it can successfully compete, prosper, and be secure in the 21st century's rapidly evolving global marketplace. The report led to the passage of the America COMPETES Act of 2007 (Creating Opportunities to Meaningfully Promote Excellence in Technology, Education, and Science). *http://www.utsystem.edu/competitive/files/RAGS-fullreport.pdf*

Rising Above the Gathering Storm, Revisited: Rapidly Approaching Category 5 (2010). National Academy of Sciences, National Academy of Engineering, and Institute of Medicine of the National Academies. A follow up to the original *Rising Above the Gathering Storm* that outlines the continuing critical need for federal funding, policy changes, and scientific and technological advancements to sustain America's competitiveness in the global economy. *http://www.nap.edu/catalog/12999/rising-above-the-gathering-storm-revisited-rapidly-approaching-category-5*

Research Universities and the Future of America: Ten Breakthrough Actions Vital to Our Nation's Prosperity and Security (2012). Committee on Research Universities; Board of Higher Education and Workforce; Policy and Global Affairs; National Research Council of the National Academies. A follow-up report to *Rising above the Gathering Storm,* developed for federal policy makers, examining the organizational, intellectual, and financial capabilities of the United States' public and private research universities—which lay the groundwork for the country's competitive advantages through research and doctoral education—as they compare to universities around the world. *http://www.nap.edu/read/13396/chapter/1#iii*

Making Value: Integrating Manufacturing, Design, and Innovation to Thrive in the Changing Global Economy: Summary of a Workshop (2012). Kate S. Whitefoot & Steve Olson (Editors). National Academy of Engineering of the National Academies. Provides summaries of workshop topics addressing how to position the United States to thrive in the new world of manufacturing, including an examination of innovation, design, and making value. *http://www.nap.edu/download/13504*

Making Value for America: Embracing the Future of Manufacturing, Technology, and Work (2015). Nicholas M. Donofrio and Kate S. Whitefoot (Editors). Committee on Foundational Best Practices for Making Value for America. National Academy of Engineering. Examines the forces and challenges of globalization, technological developments, and new business models that are transforming the way products and services are conceived, developed and distributed in the United States and around the world. *http://www.nap.edu/catalog/19483/making-value-for-america-embracing-the-future-of-manufacturing-technology*

Making Things: 21st Century Manufacturing and Design (2012). Prepared by Steve Olson for the National Academy of Engineering of the National Academies. A report of the forum, Making Things: 21st Century Manufacturing and Design, held during the NAE's 2011 annual meeting that summarizes the discussion among business, government and academic leaders about the importance of manufacturing and the opportunities and responsibilities it poses for the engineering profession. *http://www.nap.edu/catalog/13313/making-things-21st-century-manufacturing-and-design-summary-of-a*

Grand Challenges for Engineering (2008). National Academy of Engineering of the National Academies. This report proposes fourteen engineering challenges in the areas of sustainability, health, vulnerability, and joy of living—identified by experts worldwide—that are considered both achievable and sustainable for helping people and the planet survive. The report: *http://www.engineeringchallenges.org/File.aspx?id=11574&v=ba24e2ed.* The website: *http://www.engineeringchallenges.org/*

Grand Challenges for Engineering: Imperatives, Prospects, and Priorities: Summary of a Forum (2016). Prepared by Steve Olson for the National Academy of Engineering. A follow-up to the 2008 Grand Challenges for Engineering report in which seven of the eighteen experts who formulated the challenges discuss their perspectives about the impact of the original report and what has transpired in the intervening years. *http://www.nap.edu/download/23440*

U.S. Competitiveness and Innovation in the 21st Century: Why an Eternal Optimist is Worried (February 2011). Video of Charles Vest's address delivered at the National Academy of Sciences and National Academy of Engineers' event, Distinctive Voices Program: Insights on Science, Technology, and Medicine. *https://www.youtube.com/watch?v=E3pZtwj4OuI*

Conservations with History: Leading MIT into the 21st Century, A Conversation with Charles M. Vest (September 12, 2005). The Institute of International Studies, University of California at Berkeley. Video of UC Berkeley's Harry Kreisler interviewing Charles Vest about the challenges facing research universities in the information age and after the 9/11 attack. *https://www.youtube.com/watch?v=VCSxOOYfePI*

Charles Vest's Selected Honors and Awards

- Honorary doctoral degrees from eighteen universities
- The 2006 National Medal of Technology from President George W. Bush for "visionary leadership in advancing America's technological workforce and capacity for innovation through revitalizing the national partnership among academia, government, and industry"
- The 2011 National Science Board's Vannevar Bush Award "for tireless and visionary leadership in championing the role of the modern American research university as an innovation engine focused on developing scientific and technological solutions to benefit society, and as a leading voice for strengthening gender and ethnic diversity in higher education"
- Served on the President's Committee of Advisors on Science and Technology during the Clinton and Bush administrations
- Chaired the Task Force on the Future of Science Programs at the Department of Energy
- Chaired the Committee on the Redesign of the International Space Station, at President Bill Clinton's request, which rejuvenated the space station at a time when its future was uncertain
- Vice-Chairman of the U.S. Council on Competitiveness from 1996-2004

Appendix A

Excerpts from National Academy of Engineering Forum on "Making Things"

Brief Notes by Caulton (Carl) L. Irwin
Director, TransTech Energy Research and Business Development Program | NRCCE - Energy Efficiency Division

As part of its 2011 annual meeting, the National Academy of Engineering held a public forum October 17 titled, "Making Things: 21st Century Manufacturing and Design." An expert panel convened by NAE president Charles M. Vest explored many facets of contemporary manufacturing and design, addressing questions such as: What lies ahead in this world of globalization, open innovation, biology-based manufacturing, and next-generation robotics? How do we inspire and educate students to create the next wave of design and manufacturing breakthroughs? What will be the ramifications for jobs in the United States?

Although energy was barely mentioned in the NAE forum, similar questions could certainly be asked about manufacturing and design opportunities, challenges and solutions for energy technologies needed for a sustainable and competitive economy of the future.

Selected excerpts taken from panelists' presentations and the Q&A session are given below. To view a complete video of the Forum go to *http://fednet.net/nas101711/*.

Dr. Vest introduced the panel and provided introductory comments.

Craig R. Barrett, former Chairman and CEO, Intel Corporation; present Chair of Change the Equation, *http://www.changetheequation.org/*

For manufacturing and design to exist in the United States, individuals involved must add value. Education is the most fundamental part of this and K—12 education in the United States is mediocre among the 34 Organization for Economic Cooperation and Development countries. (U.S. ranks 17th in reading, 31st in math, and 23rd in science, *http://ourtimes.wordpress.com/2008/04/10/oecd-education-rankings/*). U.S. immigration policy and U.S. tax policy are further disincentives for putting high-tech manufacturing in this country. All talk and no action characterizes most of the problems of the U.S. today. In education, we have been getting the same recommendations since the 1950s. It's not that we don't know what to do, but rather that as a country we are frozen in place. The U.S. has to want and earn the right to have jobs here. At this point, the U.S. is not serious about competing.

Rodney A. Brooks, Founder, Chairman and CTO of Heartland Robotics, MIT Professor Emeritus

High-tech has had a huge run in the last 50 years, but we have neglected the low end stuff. We have pursued manufacturing research at the high end, while lower value manufacturing has gone to China and other countries. Losing low-value manufacturing means we also lose the place where that innovation happens. We need to get technology down to the factory floor, e.g., ordinary workers programing robots and using the newest high-tech tools.

Lawrence D. Burns, former Vice President for R&D and Strategic Planning, General Motors Corporation

I view manufacturing as a value adding work system that turns resources into "experiences" desired by customers. Here are a few lessons I learned while at GM: i) Manufacturing must be viewed as an integrated system. This includes designing, engineering, sourcing, producing, distributing, marketing and selling products. ii) Innovation is perhaps the only truly sustainable advantage for manufacturers. When industries are disrupted, incumbents generally do poorly. For this reason, I feel the best approach is to "do unto yourself before others do unto you." iii) Manufacturing innovation is still quite young. I have witnessed extraordinary breakthroughs during my career, but I think the best is yet to come. Just think what might be possible from the Materials genome, Nano-technology, Wireless integrated microsystems, Digital manufacturing, Advanced robotics, High performance computing, Intelligent machine-to-machine systems, and "Cradle-to-cradle-to-cradle" design.

Ursula M. Burns, Chairman and CEO, Xerox Corporation

That a nation "needs to produce well in order to live well" is a no-brainer. But we have lost sight of the formula for success and we are running out of time to fix it. We have a poor educational system; a tax structure that drives companies out of this country; an immigration policy that drives skilled candidates out of this country; trade policies that make it difficult to trade things outside this country; and fundamental flaws with how we protect IP around the world. All in leadership positions need to be a lot more impatient with the status quo—celebrate impatience and make it the virtue by which we do business every day.

Regina E. Dugan, Director, Defense Advanced Research Projects Agency (DARPA)

Our economy is an innovation economy. DARPA's primary focus is reducing the time and dramatically increasing the number and diversity of those who participate in the innovation process associated with making things. DARPA's manufacturing investment over the next five years will be approximately $200 million per year—a total of $1 billion.

Brett P. Giroir, Vice Chancellor for Strategic Initiatives, the Texas A&M University System and Executive Director of the National Center for Therapeutics Manufacturing

Texas A&M is home to the National Center for Therapeutic Manufacturing, a $35 million facility that is bringing modularity to bio-manufacturing. As part of the Center, DARPA has invested heavily in a plant-based pharmaceutical manufacturing facility, lowering barriers to entry for development and production of new vaccines.

David Kelley, Founder and Chairman of IDEO and Stanford University Professor of Mechanical Engineering

IDEO helps individuals and organizations with their creative confidence through a human centered, step by step, design thinking process. The process focuses on deep empathy for customers, a bias toward action, culture prototyping, and radical collaboration.

Appendix B

Emily Dawn Calandrelli

Remembering Morgantown Native, Former MIT President, Charles M. Vest

March 9, 2014

"After being diagnosed with pancreatic cancer, I asked him 'Are you angry? Do you think, why me?'

He said no. He said he felt extraordinarily lucky. He said, 'Who'd have thought that a boy from Morgantown would get to do so many amazing things - to speak with US presidents and vice presidents, meet the Dalai Lama, and even the Queen of England.' "

West Virginians grow up learning, memorizing, and touting famed individuals who have hailed from our wild and wonderful state. Our parents make sure to tell us all about Don Knotts, Chuck Yeager, Jennifer Garner, Steve Harvey and Jerry West. And if anyone ever speaks publicly about how amazing West Virginia is – or makes us look good in any way – we West Virginians make it spread like wild fire.

In my household, one famed West Virginian was talked about more than the others. As I grew an interest in math and science, my dad starting telling me of a lesser known, but no less successful person from Morgantown, WV. As if he were his own best friend, my dad would brag about the accomplishments of Charles Vest – Morgantown High School and West Virginia University alumna who went on to become the President of MIT. We had the same academic foundation, and so he became a living symbol of what someone from my own hometown who went to WVU could accomplish.

On December 12th, 2013, Chuck Vest died of pancreatic cancer. This past week, I attended his memorial service at MIT and I learned more about him in that 90 minutes than I had my entire life. Two of his accomplishments stuck out to me the most, and extend much further beyond his title.

1. Agent of Change for Equality for Female Professors

The first is that he spoke out and revealed inconvenient truths about gender-equity problems for MIT women faculty members. Apparently, in the 90's, there was a lot of talk about how women faculty members at universities were often times getting the short end of the stick (think smaller salaries, smaller lab space, fewer resources, etc). But in 1999, MIT released a study confirming that such inequalities were true at its own institution.

At the memorial service, faculty members stated that Chuck Vest could have easily pushed responsibility for this down the line of command, and the report could have eventually been pushed under the rug. But instead, he used his position of power to shed significant light

on the problem and spearhead initiatives to change them. Leaders from around the world followed suit, and helped rectify inequality issues at their own universities. Chuck Vest reported receiving emails from women around the world thanking him for taking on this issue.

2. Spearheaded the Open Educational Resources Movement

The second accomplishment that stood out in my mind was his leadership in the movement to make MIT's educational materials online – for free – for everyone. This initiative became known as MIT's OpenCourseWare which has helped usher in the "open educational resources" movement.

While this may not seem revolutionary today, you could imagine reasons why the president of one of the top universities in world would not want to do this. It would be a great public resource - sure, but it also means that students from around the world may not actually have to attend (and pay to attend) MIT to receive an MIT education. But he pushed for it anyway, and now universities around the world have started to develop their own open educational resources as well. I'd say, this is just a pretty big win for humanity.

So, fellow West Virginians, as you continue to brag about the coolest people who have come from our beautiful state, remember to include Chuck Vest - A Morgantown native with humble beginnings and a West Virginian twang who improved equality in the academic world and helped lead the movement to provide free education for everyone.

(http://www.thespacegal.com/blog/2014/3/9/remembering-morgantown-native-former-mit-president-charles-m-vest)

Morgantown, WV, native Emily Calandrelli is the host and producer of Xploration Outer Space, a contributing writer at TechCrunch where she writes on technology developments in the space industry, and a correspondent for Bill Nye Saves the World on Netflix. She earned a bachelor's degree in Mechanical and Aerospace Engineering from West Virginia University and masters' degrees from MIT in Aeronautics and Astronautics, and Technology and Policy.

Morgantown native Emily Calandrelli meeting Chuck Vest in 2010. *Photo courtesy of Emily Calandrelli.*

TransTech Energy Research and Business Development Program

A program of West Virginia University's National Research Center for Coal and Energy

Promoting New Companies and Commercializable Projects for America's Energy and Manufacturing Transitions

TransTech Energy (TTE) refers to transitional technologies, strategies, products and processes that move us along the pathway to a lower carbon, industrially vibrant, and sustainable economy of the future. The TTE Business Development Conference promotes investment in and nurturing of new companies and commercializable projects that can provide solutions to energy, environmental, and economic development challenges such as creating new companies, good jobs and prosperous communities.

TransTech Energy technologies:

- Reduce Greenhouse Gas Emissions,
- Improve Industrial Competitiveness, Increase Demand For Advanced Manufacturing Processes, And Create New Business Development Opportunities,
- Are Generally Available For Implementation In The Near Term Yet Present Research Challenges To Achieve Greater Effectiveness In The Future, And
- Enable Energy-Intensive Manufacturing Companies And Fossil Energy Industries To Reduce Emissions And Improve Efficiencies.

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