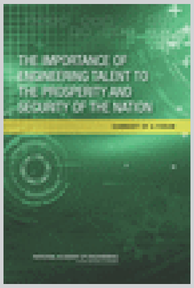

The Importance of Engineering Talent to the Prosperity and Security of the Nation: Summary of a Forum

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THE IMPORTANCE OF ENGINEERING TALENT TO THE PROSPERITY AND SECURITY OF THE NATION

SUMMARY OF A FORUM

Prepared by Steve Olson
for the
NATIONAL ACADEMY OF ENGINEERING
OF THE NATIONAL ACADEMIES

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Opinions, findings, and conclusions expressed in this publication are those of the forum participants and not necessarily the views of the National Academy of Engineering.

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THE NATIONAL ACADEMIES

Advisers to the Nation on Science, Engineering, and Medicine

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The **National Academy of Engineering** was established in 1964, under the charter of the National Academy of Sciences, as a parallel organization of outstanding engineers. It is autonomous in its administration and in the selection of its members, sharing with the National Academy of Sciences the responsibility for advising the federal government. The National Academy of Engineering also sponsors engineering programs aimed at meeting national needs, encourages education and research, and recognizes the superior achievements of engineers. Dr. C. D. Mote, Jr., is president of the National Academy of Engineering.

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Preface

The quality of engineering in the United States will only be as good as the quality of the engineers doing it. The recruitment and retention of talented young people into engineering therefore need to be top national priorities, given the crucial importance of engineering to our prosperity, security, health, and well-being. Yet I do not see engineering talent receiving nearly the attention it should.

Only 4.4 percent of the undergraduate degrees awarded by US colleges and universities are in engineering, compared with 13 percent in key European countries (the United Kingdom, Sweden, Finland, Denmark, Germany, and France) and 23 percent in key Asian countries (India, Japan, China, Taiwan, South Korea, and Singapore). In other words, more than one in five graduates of these Asian countries receives a degree in engineering, compared with fewer than one in twenty graduates of a US university. In the past, the United States has been able to attract engineering graduate students and professionals from other countries to meet the need for engineering talent in the public and private sectors. But other countries are providing increasingly attractive opportunities for engineers, with excellent salaries, facilities, and economic growth potential. The United States can no longer assume that the best engineering talent in the world will want to come to this country.

At the 2013 annual meeting of the National Academy of Engineering, the morning of the second day was devoted to a forum entitled "Importance of Engineering Talent to the Prosperity and Security of the Nation." Moderator Christine Romans, host of CNN's *Your Money* program, introduced the six forum speakers as a "superstar panel."

- Subra Suresh, president of Carnegie Mellon University and former director of the National Science Foundation, described four global trends that are reshaping how engineering talent is generated and deployed worldwide.
- John Montgomery, director of research at the US Naval Research Laboratory, outlined challenges that the US military faces in attracting top engineering talent—and some measures to address them.
- Alec Broers, who spent nearly 20 years doing research at IBM in the United States before returning to Britain and receiving a knightship for his service to higher education, drew contrasts between the United States and the United Kingdom to identify strengths and weaknesses in both countries.
- Marie Thursby, Regents' Professor who holds the Hal and John Smith Chair in Entrepreneurship at the Scheller College of Business at the Georgia Institute of Technology, explained some subtleties in the supply and demand figures for engineers and elucidated the importance of cross-disciplinary connections for engineers.
- William Banholzer, chief technology officer and executive vice president at the Dow Chemical Company, affirmed the need for engineers to make new discoveries practical and affordable.
- David Baggett, founder and head of Arcode Corporation, made the case for identifying and nurturing the elusive "ten-x" programmer—the individual who, by producing an order of magnitude more code than an average programmer, can propel companies to success.

One remarkable aspect of the panel was its range of perspectives. It encompassed the public and private sectors, US- and foreign-based firms, big companies and small. Yet all six speakers agreed that the creation and wise use of talent is the greatest opportunity and challenge facing engineering today. Their suggestions and recommendations constitute an agenda for action.

Dan Mote, President
National Academy of Engineering

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I

Talent in the Engineering Enterprise

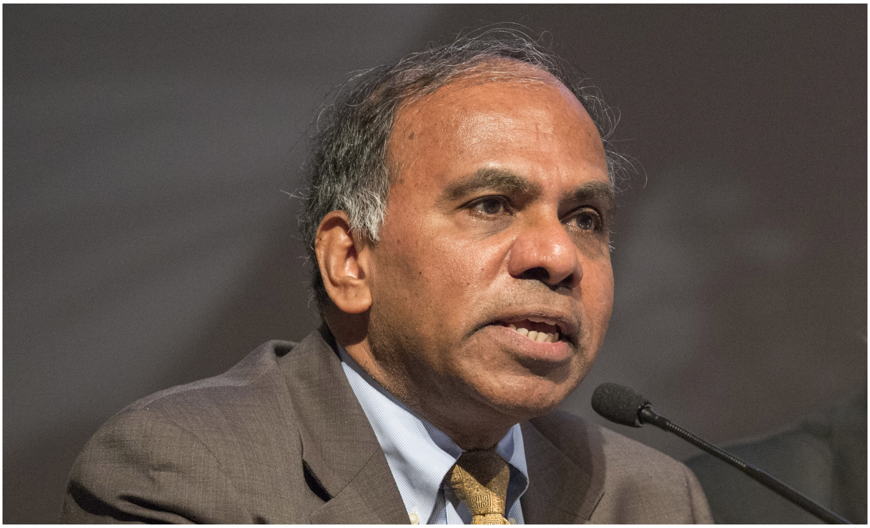
In the first half of the forum on engineering talent and its importance to the prosperity and security of the United States, the six speakers presented their perspectives on the importance of talent in engineering. Their conclusion? The competition for engineering talent will become increasingly fierce, since without talent, success is unattainable.

GLOBAL SHIFTS AFFECTING ENGINEERING TALENT

Four major trends on a worldwide stage have been shaping the generation and use of engineering talent in recent years, said Subra Suresh, president of Carnegie Mellon University and former director of the National Science Foundation.

First, investments in research and education, which both create and support talent, have grown substantially, especially in Asia. In 2012 the total worldwide investment in research and development was an estimated $1.4 trillion, split in roughly equal portions among the Americas, Europe, and Asia. However, as R&D investments in Asia—and especially in China—continue to rise rapidly, Asian R&D will soon represent a larger investment than is being made in either the Americas or Europe. In fact, the R&D investments of the top ten Asian countries have already surpassed those of the United States for the first time in history.

Second, shifting demographics are transforming the hunt for talent. Between 2002 and 2009, enrollment of first-year undergraduates in the European Union, Japan, and United States remained relatively flat. But in China, such enrollment nearly doubled and is now about equal to that of the European Union, Japan, and United States combined. Furthermore, in Asia, 19.2 percent of all college graduates are engineers;



Subra Suresh, president of Carnegie Mellon University and former director of the National Science Foundation

in the European Union, 12.1 percent are engineers; and in the United States, just 4.4 percent are engineers, down from about 7 percent two decades ago, with women engineers making up just 1.4 percent of all US college graduates.

Third, grand challenges on a global scale, such as those articulated by the National Academy of Engineering in 2008, require global solutions.[1] Societies will need to recruit talent not only from within their own borders but worldwide if they hope to solve these problems.

> The United States has benefited greatly from foreign-educated engineers for the past 60 years. "I know. I was one of them."
>
> *Subra Suresh, Carnegie Mellon University*

Fourth, the policies that create talent are local or national, but the output of that talent has no borders. Today's borderless knowledge enterprise creates questions for which answers do not yet exist, Suresh observed:

[1] Information about the NAE's Grand Challenges for Engineering is available at www.engineeringchallenges.org.

- Who will develop policies and ensure compliance for the shared and collaborative global scientific enterprise?
- Who will organize, distribute, and store scientific information, including the big data generated by information technologies?
- Who will pay to archive and curate scientific information across rapidly changing platforms?
- Who will create policies that protect privacy, confidentiality, and intellectual property?
- Who will develop validation for a massive online educational enterprise and ensure that it has the right quality on a global scale?
- How will institutions and individuals participate in a global enterprise through open access to publication and data while addressing national and local needs, and who will pay for that access?

Some organizations are starting to think about these questions. Two years ago, the major research funding agencies from around the world gathered at the National Science Foundation and formed the Global Research Council, which represents about 98 percent of science and engineering funding in the world. The group is examining how to coordinate and pay for initiatives addressing these issues. “This is going to be a critical part of the global talent enterprise,” Suresh said.

The United States was the unquestioned innovation leader in the second half of the 20th century, Suresh acknowledged, but it did so partly by attracting and retaining talent from around the world. A quarter of all the American recipients of the Nobel Prize received their first degree abroad, as did a quarter of all the members of the National Academy of Sciences. The education of foreign scientists and engineers in other countries who subsequently work in the United States represents a tremendous subsidy to US innovation. “That is what we have benefited from for the last 60 years,” said Suresh. “I know. I was one of them.”

ACCESSING TALENT IN THE US MILITARY

Military systems must be state of the art and therefore require world-class scientists and engineers who can generate knowledge, harvest knowledge from elsewhere, and collaborate worldwide. Ensuring access to this scientific and engineering talent in turn requires interesting work, good facilities, and competitive pay, observed John Montgomery, director of research for the Naval Research Laboratory.

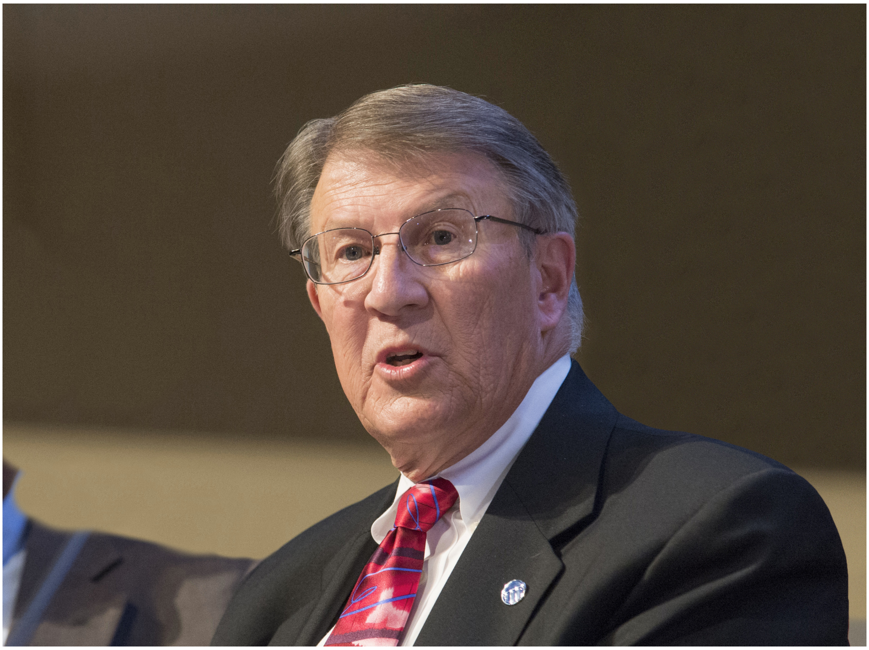
Each military service has a separate laboratory research system, such as the Army Research Laboratory headquartered in Adelphi, Maryland; the Naval Research Laboratory in Washington, DC; and the Air Force Research Laboratory in Dayton, Ohio. Each service also has numerous engineering and medical research centers, representing more than 200 sites with technical capabilities in the Department of Defense. These research organizations work on everything from basic science to the essential tools of current military art. They seek to maintain the DOD's technological base and build on knowledge from around the world. They also provide advice to senior leadership and the managers of acquisition and operational programs where technological resources have to be brought to bear quickly to deal with crises or military issues, such as the use of improvised explosive devices in Iraq and Afghanistan.

DOD laboratories have approximately 61,000 employees, including 35,000 scientists and engineers, and account for about $20 billion in funding per year. About three-quarters of the technical workforce are engineers and about one-quarter scientists. Of the scientists, 10 percent are PhDs and 27 percent have master's degrees, though in a facility like the Naval Research Laboratory more than half have PhDs. The Department of Defense as a whole employs about 150,000 scientists and engineers, representing about 2 percent of the national STEM workforce.

> "In my 45 years in the business, I have never been bored for an instant. I cannot imagine a better life that somebody could have."
> *John Montgomery, Naval Research Laboratory*

The military would seem to have access to a wealth of scientific and technological expertise, but the availability of talent is in fact a major concern, Montgomery observed. Only US citizens with security clearances can work in DOD laboratories and centers. Also, to harvest knowledge worldwide, the Department of Defense needs more collaborations with international scientists and engineers, and US science and technology needs to remain at the cutting edge to interest potential collaborators.

R&D in the United States is becoming a smaller part of a larger whole as technology becomes increasingly global. In particular, the center of gravity of global research is shifting eastward as R&D expenditures in Asia expand. Today, the Naval Research Laboratory has about



John Montgomery, director of research for the Naval Research Laboratory

1,200 collaborations with colleges and universities, but only about 200 of those are with colleges and universities in other countries. "We need to do more of that," said Montgomery.

The Defense Department, Office of Science and Technology Policy, State Department, and Immigration and Naturalization Service are working on an initiative to provide a fast track to citizenship for highly qualified foreign graduates of colleges and universities who might wish to remain permanently in the United States. Such a program would be a way to retain the best and the brightest young engineers for work in US laboratories.

In an increasingly technical world, existing disciplines will grow and new disciplines will emerge, which will require more diverse skills. Engineers will need not only mathematics and computer skills but the abilities to design, build, innovate, and communicate. These skills are not easy to nurture, and the engineering curriculum is already densely packed.

Other professions compete for talent. As Montgomery pointed out, the average scientist or engineer at the Naval Research Laboratory may earn just under $100,000 a year, which is substantially less than might be earned in other jobs. Scientists and engineers also need the flexibility to do the science they want to do to build their careers. In addition, many entry-level engineering jobs are moving offshore. "How are we going to get them [back]?" Montgomery asked.

A valuable tool for the Department of Defense has been to invite students into laboratories to do research early in their education with highly skilled scientists and engineers. The Naval Research Laboratory brings in about 500 students every year from high school through graduate school and about 140 postdoctoral fellows and embeds them with scientists and engineers, after which many come to work at the laboratory. "That is a model that can be very useful," said Montgomery. "Nothing is more exciting than to be a young scientist or engineer… embedded with a large cadre of those folks who are really excited about what they do."

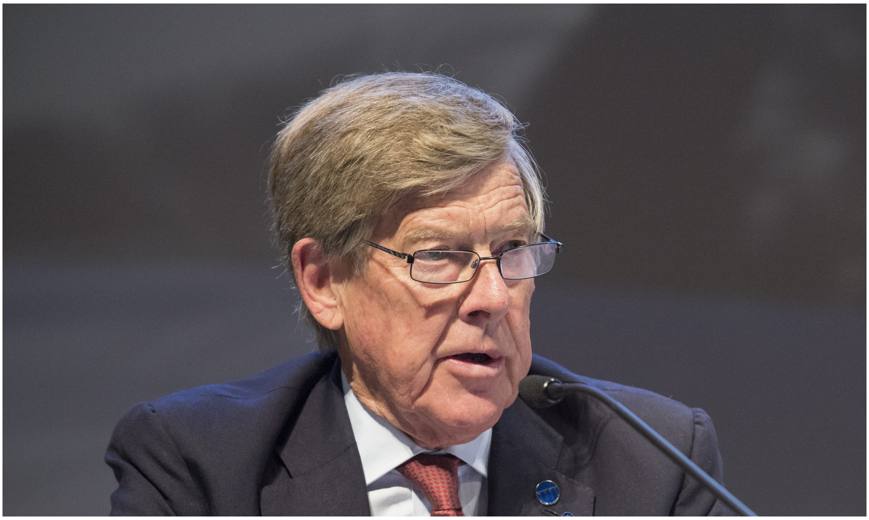
The level of appreciation for engineers is high, Montgomery concluded, and the work is interesting and challenging. "In my 45 years in the business, I have never been bored for an instant," he said. "I cannot imagine a better life that somebody could have."

RAISING THE PROFILE OF ENGINEERING IN THE UNITED KINGDOM

Alec Broers, a member of the House of Lords in the United Kingdom and past president of the Royal Academy of Engineering, reminded the forum attendees that the United States remains dominant internationally in high technology. But the world is changing and faces serious problems that can be resolved only by engineers, so "we need very talented people," he said.

> The Queen Elizabeth Prize for Engineering is designed to recognize work "where engineers have changed the world for the better in a big way."
>
> *Alec Broers, past president of the Royal Academy of Engineering*

The United Kingdom offers a telling contrast to the United States. It spends only 1.7 percent of its gross domestic product on R&D, which is lower than most other western countries. It does not produce enough UK-born engineers to meet the needs projected for the next decade. According to Broers, the



Alec Broers, member of the House of Lords in the United Kingdom and past president of the Royal Academy of Engineering

United Kingdom needs to increase its output of engineers by 50 percent, "[and] I do not know quite how we are going to do that."

The top universities in the United Kingdom are getting well-qualified students, but others have trouble attracting students with adequate skills, especially in mathematics. "We are not going to create modern engineers if they do not have mathematical competence," Broers said. Furthermore, among the students who receive engineering degrees, about a quarter go into professions that are not based on science and technology. And many overseas students educated in the United Kingdom are returning to their home countries once they graduate, in part because visa policies do not encourage them to stay.

Young people in the United Kingdom do not know much about engineering. A survey of 12- to 16-year-olds found that less than 20 percent knew what a modern engineer does, and only 38 percent considered engineering a respectable career. In part because of overly cavalier use of the term "engineering," students and their parents tend to confuse engineering with jobs for technicians such as mechanics, servicemen, and linemen. "There is immense ignorance out there," said Broers.

The outlook is not entirely negative, Broers added. The United Kingdom has managed to maintain a flat governmental budget for science, engineering, and technology despite cuts in most other areas. And engineers in the United Kingdom receive a significant salary premium—amounting to about 15 percent compared with other graduates. But engineering companies still tend to be conservative in creating incentives for engineers, causing them to lose potential employees to other sectors.

The UK government is trying to improve the situation by attracting engineers and tying engineering more strongly to the global community of science and technology. In particular, Broers described the new international Queen Elizabeth Prize for Engineering, which has joined the Draper Prize and the Finnish Millennium Technology Prize among the top international prizes for engineering. Administered by the Royal Academy of Engineering, it is overseen by an independent board of trustees, has strong backing from the royal family, and has succeeded in raising $40 million.

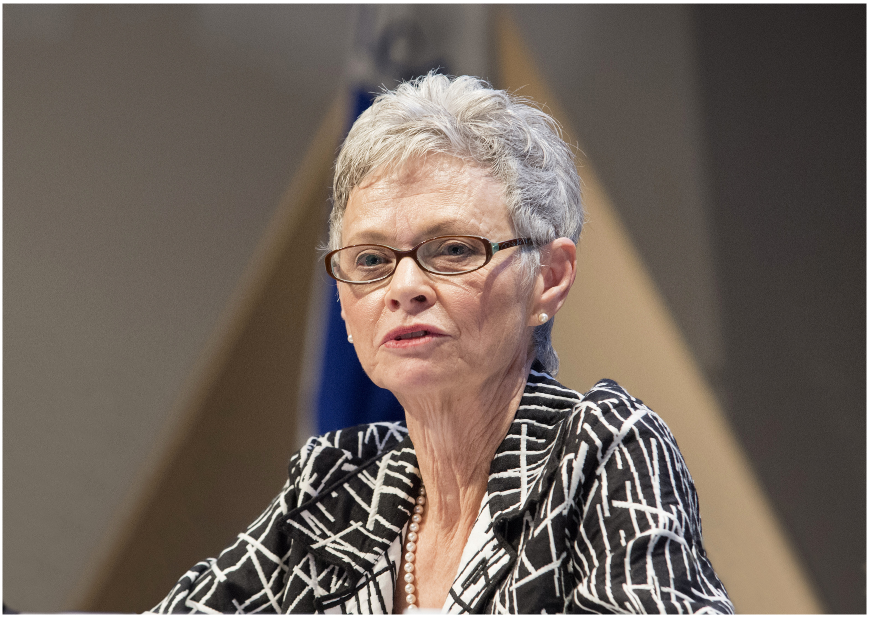
The winners of the first Queen Elizabeth Prize were announced in March 2013: Louis Pouzin, Robert Kahn, Vint Cerf, Marc Andreessen, and Tim Berners-Lee for their contributions to the creation of the Internet and the World Wide Web. The queen presented trophies and checks on June 25 at an event attended by the prime minister and many political leaders. The winners of the prize, both by example and by promoting engineering, are expected to increase the visibility and profile of engineering in the United Kingdom and elsewhere and attract more talented students to the field. The goal, said Broers, is to recognize work "where engineers have changed the world for the better in a big way."

ENGINEERS AS CONNECTION MAKERS

The number of engineering degrees awarded in the United States has actually risen over the past decade—by 40 percent at the undergraduate level, 24 percent at the master's level, and 71 percent at the PhD level, noted Marie Thursby, Regents' Professor and Hal and John Smith Chair in Entrepreneurship at the Georgia Institute of Technology's Scheller College of Business. Furthermore, the number of US PhDs granted in engineering is much higher than for any scientific field other than the biological sciences, and has increased dramatically over the past century.

> Combining both breadth and rigor in engineering education is "no mean task."
> *Marie Thursby, Georgia Tech*

Although the United States will never match China in the produc-



Marie Thursby, Regents' Professor and Hal and John Smith Chair in Entrepreneurship at the Georgia Institute of Technology's Scheller College of Business

tion of engineers, Thursby pointed out that the competitive advantage of engineering in the United States is the ability of US-educated engineers to make connections. She went on to explain that, while much of the economic growth in the United States for the past 60 years has come from technological change and innovation, innovation is the adoption of inventions, not the invention itself, and engineers have been pivotal in enabling this adoption.

On the other hand, the demand for engineers is currently not as strong as some might suppose. Definite commitments for engineering PhDs—meaning either job offers or postdoctoral positions—have declined since 2001, and a growing number of engineering PhDs have been going into postdoctoral fellowships rather than into jobs. Projections from the Bureau of Labor Statistics for growth in engineering jobs from 2008 to 2018 are only slightly higher than for growth in all occupations. Furthermore, real wages for engineering graduates have been more or less constant during the last 20 years, which does not indicate a rosy job outlook.

But engineers contribute to the economy even when they are not working directly in engineering. Of the 12.6 million people in the United States in 2008 whose highest degree was in science or engineering, only 3.9 million were in science and engineering occupations, and for another million working in those occupations their highest degree was in a field other than science or engineering. However, many of the other 8.7 million people with science and engineering degrees were in jobs closely related to those fields, suggesting to Thursby that they are working on problems at the intersections of fields.

Indeed, surveys of engineering jobs have revealed that engineers increasingly are working on cross-functional and often globally distributed teams. Universities have responded to this trend by developing programs that broaden engineering. Undergraduate programs with an additional year of specialized study—so-called four plus one programs—are one approach, as is the creation of a minor in entrepreneurship, partly in response to the number of engineers who are starting their own companies. Joint degree programs at the graduate level combine engineering with degrees in law or business. An innovative two-year program at Georgia Tech teams PhD candidates in science and engineering with business and law students to focus on issues in commercializing fundamental research.

Engineers still need to be technically superior, Thursby noted, so a broader education cannot lose its rigor, which "is no mean trick." But innovative approaches to engineering education can help produce not just chief technology officers but chief executive officers.

RETAINING ENGINEERING'S PLACE IN SOCIETY

Discovery is often celebrated as the realization of human dreams, said William Banholzer, chief technology officer and executive vice president at the Dow Chemical Company. But innovation occurs when discoveries are applied and put to work doing something useful. Edison, Ford, and Bell did not invent the devices with which they are associated, but they were the first to make them practical and cheap enough to afford. In contrast, the invention of buckyballs won a Nobel Prize but has not resulted in commercial products. Engineers are experienced at making new discoveries practical and affordable, said Banholzer, but to retain their unique place in society they need to do a better job of explaining the value they create for society.

Similarly, the United States may be preeminent in technology now, but it has no guarantees of remaining on top, and no charter or law requires corporations to do research. Companies need to create value for their customers in order to have the resources to pay for research. Asian companies have figured this out and are trying to overcome the United States' lead. "We have to be very jealous and guard the unique position we have right now, and talent is first and foremost."

At the same time, an English-speaking jet-lagged engineer cannot go to China to solve a problem. Trained engineers are needed there to solve the problem. "Brains are globally distributed, and we have to maximize the assessment of talent across the globe."

> "Strategy is good, but talent is what allows you to execute, and there is nothing more important than talent."
> *William Banholzer, Dow Chemical*

An engineering education is superb background for a job in the private sector, government, or academia, Banholzer concluded. It is a great background for marketing, manufacturing, and business leadership—many highly successful CEOs started in engineering. When the leaders of companies are engineers, they understand the technology as well as the needs of the broader enterprise. Leaders know that the cultivation of talent is the single most

William Banholzer, chief technology officer and executive vice president at the Dow Chemical Company important thing they do. “Strategy is good, but talent is what allows you to execute, and there is nothing more important than talent,” said Banholzer.

FINDING AND NURTURING THE TEN-X PROGRAMMER

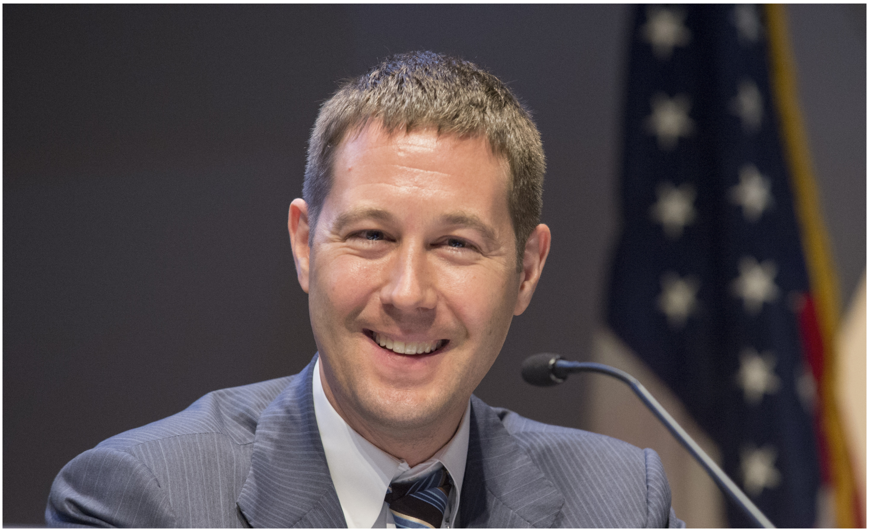
David Baggett has been involved in building three companies, one of which was sold to Sony and a second to Google. His current company, Arcode, is working to revolutionize the email user experience. Companies like his rely on a particular kind of engineering talent, he said. Some programmers can write ten times as much high-quality, documented, and maintainable code as a typical programmer at a large software company, and sometimes much more. Even large companies like Google, Facebook, and Twitter rely extensively on such programmers.

The reason some programmers can be so much more productive is that software does not rely on physical inputs but on ideas that do not have mass or take up physical space. “A single person can manipulate a conceptually vast object in this mental space just by typing on a keyboard,” he said. Most of the big name software companies had at least one or a handful of these people early in their histories, which is “one of the reasons, if not the reason, why they are big software companies now.”

The challenge for companies is that not many ten-x programmers exist, and they can be hard to recruit and retain. Baggett, who said that he has hired just a handful of such people in his career, uses four techniques to attract them. First, he gives them interesting and hard problems to work on. Second, he gives them a tremendous amount of freedom, though that freedom is guided toward a commercial goal. Third, he protects them from bureaucracy. Fourth, he provides them with a share of the profits, despite the reluctance among business people to pay engineers high salaries. “You have to keep fighting the perception that nobody is worth that.”

> “It is a combination of depth and breadth. It is a little bit of quirkiness. This is really what leads to innovation in my experience. These people are the golden geese of our economy.”
>
> *David Baggett, Arcode*

Such individuals are hard to identify, partly because they know “a lot about a lot.” They may not have had the highest GPA or SAT scores and may have failed a class or two, but they may have mastered both the foundations of modern



David Baggett, founder, Arcode

cryptography and the biology of cephalopods. "It is a combination of depth and breadth," he said. "It is a little bit of quirkiness. This is really what leads to innovation in my experience. These people are the golden geese of our economy."

Ten-x'ers are more like artists than engineers, spending their lives learning technical things rather than learning how to paint. They may not have attended an Ivy League school or have grown up in an affluent household, and some may seem weird. But they tend to see connections across disciplines that others would not see. "These are the ones we need to attract and build our companies around."

The ten-x'er needs space in an organization "in which to run around freely and break stuff," said Baggett. Their ideas may seem crazy, but they should not be overmanaged. "What you have to say to them is not, 'Wow, that sounds really insane. That is never going to work. No one is ever going to buy that.' You have to say things like, 'Yes, I like the way you're thinking. Can we make this practical for a million people?'"

Of course, some engineering systems, such as avionic systems, need above all to work. But engineers should keep an open mind when confronted with strange ideas from otherwise accomplished and brilliant people. These individuals come from everywhere, not just the United States—a 19-year-old Sri Lankan girl who has been selling iPad games since she was 15 may be a ten-x'er. They are partly born that way and partly the product of their experiences, especially their experiences with computers.

The United States needs more people to come through the science and engineering educational pipeline, but it also needs to think about the small handful of ten-x people, "because they are the core of these small companies that become the great companies," said Baggett. Companies need to learn how to identify these people and deal with them in ways that do not destroy their motivations. Finally, the United States needs to hang a sign on its borders that says, "We are open for business," Baggett said.

II

From Weaknesses to Strengths in the Search for Engineering Talent

In the second half of the forum, the six presenters responded to questions from the moderator and forum attendees on the role of talent in engineering. The conversation ranged widely, but a recurring theme was how the United States can both rectify weaknesses and build on existing strengths to optimize its use of talent in engineering.

RECRUITING AND RETAINING YOUNG ENGINEERS

The recruitment and retention of students to engineering education and engineering careers were prominent topics of discussion. Many students come to college with an interest in engineering, often because of the potential of engineering to solve societally important problems. But an estimated 40 percent of the students who intend to get an undergraduate degree in science or engineering abandon that intention by the end of their first year, noted Suresh, which is "a huge issue today in all universities." The engineering curriculum tends to be inflexible, requiring that students take a particular sequence of classes. And options available in other disciplines, such as a junior semester abroad, are not easy to do in most engineering departments. "The apparent inflexibility of the curriculum, the rigidity of the curriculum, and the demands of the curriculum have turned a lot of students off," said Suresh.

Engineering education also can impose onerous demands on students in graduate school, especially if the time required to earn a graduate degree and acquire experience is extended. As Banholzer pointed out, those who pursue an undergraduate degree, graduate degree, and one or more postdoctoral fellowships may not get their first job until they are in their thirties, making law, medicine, finance, and other professions more attractive to many young people.

Broers agreed that students are in college and universities to get an education. Unless graduate students want to teach in a university, Broers said, "the PhD should be shortened and those people should get out and start producing things as soon as possible."

Another factor that can stymie aspiring engineers is a focus during their education on fields where an oversupply of engineers exists. Faculty members can contribute to such oversupplies by pursuing popular research topics, Banholzer noted. Engineers who are broadly trained can shift among fields, but those who have specialized on narrow topics may find themselves in trouble.

> "The PhD should be shortened and those people should get out and start producing things as soon as possible."
> *Alec Broers, past president of the Royal Academy of Engineering*

Thursby agreed, observing that the large NIH budget of recent years has drawn many people to biomedical research, to the point that too many people are now in that field. Meanwhile, the physical sciences and engineering have suffered from a lack of funding and interest.

Yet the loss of students to other fields, or to nonengineering careers if they receive a degree in engineering, should not be seen as a total loss to engineering, Thursby added. People who move out of engineering into other jobs can apply the skills and discipline they learned as engineers to those jobs. As a forum attendee pointed out, engineers can work in the patent office, become public policy analysts, work on intellectual property, become national intelligence analysts, teach in elementary schools, or run for Congress. Banholzer seconded this point, and added that an engineer can become a chief technology officer, a chief financial officer, or a chief executive officer. As Montgomery observed, engineers know how to think and understand how the world works. Having people like that in any job is a good thing.

Given the importance of making connections across fields, one way to retain people in engineering is to give them a broader view of their opportunities, said Thursby. To be successful in the modern world, companies need to pull together teams of business people, scientists, engineers, and others with a mix of skills. As an example, she cited a competition involving human-computer interfaces where a technology developed for low-vision people to interface with a computer resulted in an application to improve the productivity of people working in call centers.

Students can be attracted to engineering through the potential financial rewards of the field. For example, Thursby observed that patents are not necessarily a good way of protecting intellectual property but can be an incentive mechanism for inventors. High earnings are not guaranteed to engineers who enter high-risk startups, but a "lottery ticket kind of upside" can be a powerful incentive. Broers agreed that differential pay can be important in attracting outstanding engineers, which is a lesson that the financial world has learned but not engineering.

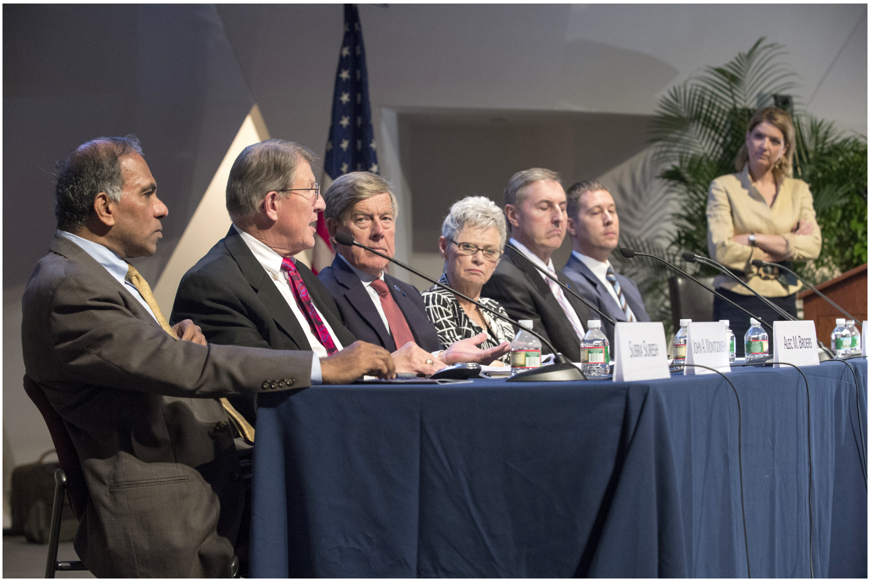
"You have to map [your work] onto something that the general population is interested in. Clearly, that is a big factor in getting kids to start on difficult engineering programs."
David Baggett, Arcode

Finally, Baggett pointed to the importance of how engineering markets itself. Engineers tend to avoid marketing, but it can be critical to progress. The Artificial Intelligence Laboratory at the Massachusetts Institute of Technology did exciting work on a wide variety of topics, but the public was most interested in robots. "You have to map [your work] onto something that the general population is interested in," he said. "Clearly, that is a big factor in getting kids to start on difficult engineering programs—because they are difficult."

On this point, Banholzer added that engineers have not done a good job of explaining their dreams. Engineering has been so successful that people take it for granted. Water is cheap and plentiful, energy is abundant, and cars work. But engineers are also the people who enable biomedical scientists to work on cures for cancer. Without engineering, research could not progress. The challenge is to make clean air, electric cars, and renewable energy as appealing as working to cure human diseases.

US WEAKNESSES

The forum occurred during the federal government shutdown of October 2013, and several presenters pointed to government dysfunction as an obstacle to the development and employment of engineering talent. The United States is the only developed country in the Western Hemisphere that does not have a multiyear budget, noted Suresh. Lately it has



CNN reporter Christine Romans and forum panelists

not had even an annual budget, instead funding the government through a series of continuing resolutions.

Budget difficulties relate directly to a question posed to Suresh during the discussion period: Should a National Engineering Foundation be established in parallel with the National Science Foundation? Several engineers have led the National Science Foundation during its history, Suresh responded, though they sometimes have encountered resistance from those who held that the foundation should always be led by a scientist. The major question is where the resources would come from for a separate foundation. The creation of the Advanced Research Projects Agency–Energy in the Department of Energy came about only after considerable advocacy by a number of organizations, including the National Academy of Sciences and National Academy of Engineering, and its budget has remained small. Until the federal budget situation becomes clearer, he said, "even the remote possibility of the creation of a new agency, with its own standalone budget, is in my personal view very unlikely."

The United States has other weaknesses. The K–12 education system does not produce enough students with strong skills and interest in science and technology, said Montgomery. Educational weaknesses also limit the ability of adults to understand science and technology and the contributions of science and technology to our lives.

In colleges and universities, the engineering curriculum is so rigid and so packed with topics that it can be difficult to teach engineers the skills they need in the modern workplace, Baggett noted. For example, they may lack the training to understand the connections among fields, even though these connections are critical to success.

US STRENGTHS

The United States also has great strengths on which it can build. Suresh cited the US education system, which instills in young people the right and prerogative to question authority from a young age. Other countries whose students score much higher than their US counterparts in international comparisons of science and mathematics would love to have a system where young people are as independent and questioning.

The United States also is willing to give young people senior responsibility, Broers noted. Though the United Kingdom has gotten somewhat better at this in recent years, students still shy away from engineering companies that will not take such risks. Letting young workers take risks is a way to keep them, even if they require continuing education. "My recipe is responsibility early with very bright people."

The willingness to let people fail, learn from their mistakes, and try again is another strength of the United States. As Banholzer said, "You cannot win by playing not to lose." Baggett agreed that the United States, in contrast to other countries, has very favorable bankruptcy laws for entrepreneurs. "In Silicon Valley, it is a badge of honor that you failed," he said.

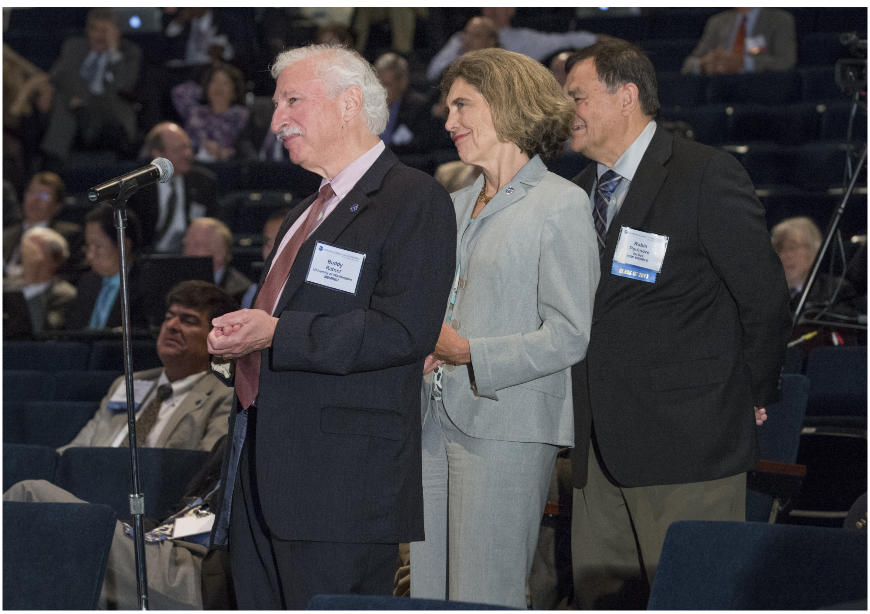
> "You cannot win by playing not to lose."
>
> *William Banholzer, Dow Chemical*

The United States has developed institutions and legal structures designed to spur advances in science and technology, Suresh said. Peer review, protection of intellectual property, procedures to safeguard research integrity, inspector general offices, and expectations for transparency were all developed and refined in the United States to foster the progress of science. And in recent years, other countries have been creating their own versions of the National Science Foundation to try to emulate its successes—even as, ironically, the foundation has come under attack from members of Congress.

The United States also has been willing to devote large amounts of resources to major initiatives. Learning how to put billions of transistors on a single silicon chip took thousands of engineers and a huge investment, not a single inventor, Broers observed. Every industry is different and requires a tailored approach, and politicians should not be deluded into thinking that a few geniuses can lead a country to the front of the world's economy.

> "My recipe is responsibility early with very bright people."
> *Alec Broers, past president of the Royal Academy of Engineering*

A final reason mentioned by Suresh for the success of the United States is that the private and public sectors are willing to take a risk on people born elsewhere and give them an opportunity. Suresh, who was educated in India, reported a recent conversation with an Indian minister who asked him how to make India a leader in science and technology. Suresh replied that when the prime minister of India is willing to hire someone who was educated elsewhere as the head of India's science funding agency, then India will have arrived.



The panel presentation prompted many questions.

INTERACTIONS WITH OTHER PROFESSIONALS

Discussion also revolved around the strengths of the United States in bringing together the disparate talents needed to solve difficult problems. Indeed, the cross-fertilization made possible by collaboration may be one reason ten-x programmers are so valuable. They can stimulate others by exposing them to different ways of thinking about a problem, said Montgomery. These innovative individuals can create different reference frames, which is why a single way of doing business may not permit them to thrive.

Engineers often work in collaborative environments, which points to the importance of being able to communicate with nonengineers. For example, most senior military officers and civilians in the Department of Defense do not have training in science or engineering, Montgomery observed. But when science and technology are explained to them in terms they can understand, the knowledge influences their decisions. When senior officials know what a science-based technology can do and why they should care about it, they can apply a different value proposition to decision making. "What we do is arcane. It is very difficult for people who are not educated in it to understand. But we are not trying to teach them how to design a radar. We are trying to make them understand fundamentally how a radar works and why they should care about it."

> "We are not trying to teach [people] how to design a radar. We are trying to make them understand fundamentally how a radar works and why they should care about it."
>
> *David Montgomery, Naval Research Laboratory*

Collaborative efforts can pose risks, several presenters noted. For example, said Banholzer, some members of a collaboration may overlook the fact that fundamentals still matter, such as the laws of thermodynamics. Collaborators need to be aware of the inherent problems in an industry if the collaboration is to succeed. Collaborators also may speak very different languages, said Thursby, depending on whether they have been educated in engineering, the law, or business.

GRAND CHALLENGES

Montgomery speculated whether a large multidisciplinary challenge could harness people's imagination and creativity in the same way that the Apollo Project did in the 1960s. Perhaps the fusion energy problem, after fifty years of work, is ready to solve? Such a challenge could draw young people into science and engineering by demonstrating that they "will really change the world and have a great time doing it."

Challenges can spur achievements, but the process also works the other way around, said Suresh. Many of the NAE's 14 grand challenges for the 21st century arose in part from the greatest engineering achievements of the 20th century published several years earlier.[1]

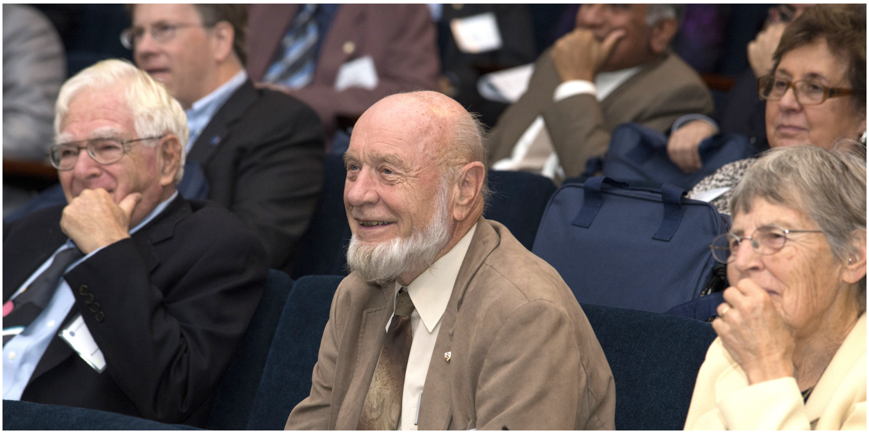
Engineering solutions can also have unintended consequences, said Suresh, even those that are enormous successes. He suggested that one way to deal with these unintended consequences may be to enhance the interface between the natural sciences and engineering and the social, behavioral, and economic sciences. For example, federal investments have made it possible to forecast with great accuracy where a tornado will strike, but public safety officials lack the ability to predict how people will respond to warnings about tornadoes, and this problem will become greater and more important as the means of communication proliferate.

Suresh also noted that President Kennedy's call to put a man on the moon, which drew hundreds of thousands of Americans into science and engineering, occurred before wheeled suitcases were invented. In other words, innovation still has plenty of low-hanging fruit. This is an argument, he said, for individual scholarships that allow 20-year-olds to come up with ideas that change the world. The United States has done a good job of uncovering and promoting those ideas for the past half century, and it needs to continue to do so. For example, the National Science Foundation funded two young people at Stanford to think about a method to rank pages on the World Wide Web, and that funding contributed to the founding of Google.

Long-term support may be needed to develop such ideas, Suresh continued. The National Science Foundation funded Andrew Wile for eight years while he was working on the proof of Fermat's last theorem, and last year's Turing Prize winner at UCLA had 24 years of continuous funding from the foundation. As Montgomery observed, hard problems can take a long time to solve, and organizations need perseverance to allow people to work long enough to solve them.

Suresh also pointed out that most of the basic research in mathematics, computer science, and engineering on which the global positioning

[1] More information is available at http://greatachievements.org.



Members and guests paid rapt attention to the forum discussion.

system is based was funded not by the Department of Defense but by basic science agencies. Without this funding, basic technologies such as GPS and cell phones would not be available. Some topics are not "sexy" at the moment, but will be half a century from now.

The federal government is currently financing several large initiatives in science and technology, Suresh observed, including the BRAIN Initiative, the National Robotics Initiative, and major projects focused on the use of big data. While none may be as captivating as putting a man on the moon, they are all big problems that could capture the interest of young people. For example, the economic implications of finding a way to prevent Alzheimer's disease could amount to many billions of dollars.

These projects motivate practicing engineers and draw new people into the field. A forum attendee reported that surveys of students and their parents show that salaries are more important to parents than to students—students want to know how their work will benefit society.

Engineering may require a rigorous course of study, but so does medicine, and plenty of students want to become physicians. Engineering too is a global force for good, Montgomery observed, and that is its greatest asset in attracting and retaining talented people.

Appendix A

Forum Agenda

Annual Meeting Forum

Importance of Engineering Talent to the Prosperity and Security of the Nation

Monday, October 7, 2013
9:30 a.m.–12:30 p.m.
National Academy of Sciences Building
Washington, DC

An expert panel will explore the many questions surrounding the importance of top-talent in the engineering workforce to the competitiveness of the US advanced economy and the future prosperity, security, and quality of life of US citizens. The Forum is held as part of the 2013 NAE Annual Meeting.

Welcome

C. D. Mote, Jr., President, National Academy of Engineering

Moderator: Christine Romans, Host of CNN's weekly business show *Your Money*

Forum Discussion

Forum Participants:

David Baggett, Founder, Arcode

William F. Banholzer, Chief Technical Officer, New Business Development, and Executive Vice President, The Dow Chemical Company

Alec N. Broers, House of Lords, and Past President, Royal Academy of Engineering

John A. Montgomery, Director of Research, US Naval Research Laboratory

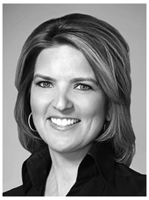
Subra Suresh, President, Carnegie Mellon University, and Former Director, National Science Foundation

Marie C. Thursby, Regents' Professor and Hal and John Smith Chair in Entrepreneurship, Scheller College of Business, Georgia Institute of Technology

Appendix B

Panelists' Biographies

CHRISTINE ROMANS is the host of *Your Money*, CNN's Saturday and Sunday business program. She also reports on the economy, politics, and international business for CNN's morning shows, and her reporting is regularly featured on CNN International. Her coverage focuses on breaking developments in the current economic crises and what they mean to Americans and their money. She is known for her "Romans' Numeral" segment, in which she deconstructs complex stories and explains what they mean for the viewer. When President Obama talks about the economic crisis and the road ahead, she provides perspective and analysis of the administration's efforts.



She investigated the collapse of Enron, WorldCom, and numerous other corporate scams and has reported on corruption from the point of view of the investor. She has also extensively covered immigration reform, substance abuse, homeland security, American foreign policy with China and Latin America, and education.

She received an Emmy Award in 2004 for her work on "Exporting America," a *Lou Dobbs Tonight* investigation into the impact of globalization on US workers. The National Foundation for Women Legislators honored her with its media excellence award for business reporting and in 2009 she was selected for the Greenlee School of Journalism's James W. Schwartz Award.

She was previously a correspondent for *Moneyline,* and before joining CNN she reported for Reuters and Knight-Ridder Financial News in the futures trading pits of Chicago. She is the author of two books:

How to Speak Money (Wiley, 2011) and *Smart Is the New Rich* (Wiley, 2010). She is a graduate of Iowa State University.

DAVID BAGGETT heads Arcode Corporation, which he founded in 2008. The company's first product, inky®, is revolutionizing the email user experience by making email smarter, simpler, and safer. Before that he cofounded ITA Software, with two other graduates of the MIT Artificial Intelligence Laboratory. The company developed the first new airfare pricing and shopping software in decades, and licensed the technology to most major US and many international airlines. Its technology powers Orbitz, Kayak, Hipmunk, and many other travel industry websites. Google purchased ITA Software for over $700 million in 2011.

Mr. Baggett studied computational linguistics with Robert Berwick in the PhD program at the MIT AI Lab, but left in 1994 to join video game company Naughty Dog, where he codeveloped the Crash Bandicoot series for the Sony PlayStation. The Crash games were worldwide bestsellers that redefined the state of the art, leading Sony to adopt Crash as its mascot. As one of two developers on the first game in the series, Mr. Baggett pioneered the use of distributed polygonal scene precomputation to vastly reduce rendering time and greatly increase scene complexity. He also introduced octree-based collision detection to the video game world, and implemented many of the level processing tools and the entire rendering pipeline.

He graduated magna cum laude with a BS/BA in computer science and linguistics from the University of Maryland in 1992, when he also received the College of Computer, Mathematical, and Physical Sciences Dean's Award for Academic Excellence. He worked extensively with Bill Pugh and Bill Gasarch in the Computer Science Department, and with Sharon Inkelas in the Linguistics Department.

WILLIAM F. BANHOLZER is an executive vice president leading Dow Chemical Company's venture capital, new business development, and licensing activities, and is also Dow's chief technology officer. He chairs the company's Innovation and New Business Development Committee, which oversees investments in new technologies and major business initiatives, and Corporate Responsibility Committee. He is also a member of the board of directors for the Dow Corning Corporation, the Dow AgroSciences Members Committee, and the Dow Foundation Board of Directors.

Dr. Banholzer sets the company's vision for science and technology and leads the execution of that vision, managing a portfolio of research programs with an annual budget of $1.7 billion. Under his leadership the value of Dow's innovation pipeline has tripled from $10 billion to over $32 billion. His efforts to accelerate the company's technology development were recognized by *R&D Magazine*, which ranked Dow in the top ten for R&D in all industries, and a recent Booz Allen study ranked the company's innovation portfolio management "Best in Class." Dr. Banholzer also received the Industrial Research Institute's Holland Award for R&D management and the Council of Chemical Research's Pruitt Award for his innovative approach to research collaborations.

Dr. Banholzer had a 22-year career with General Electric Company before joining Dow. He joined GE in 1983 as a staff chemical engineer and held a number of leadership roles, including head of R&D for superabrasives and of GE lighting. He received numerous GE honors: the Bronze, Silver, and Gold Patent Awards; Superabrasives Leadership Award; Plastics CEO Six Sigma Award; and election to the Whitney Gallery of Technical Achievers. He left GE as vice president of global technology at GE Advanced Materials, where he was responsible for worldwide technology and engineering.

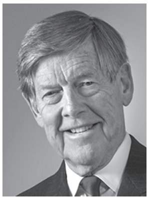
Dr. Banholzer earned a bachelor's degree in chemistry from Marquette University and master's and doctoral degrees in chemical engineering from the University of Illinois. He is a certified Six Sigma Master Black Belt.

ALEC M. BROERS spent nearly 20 years in research with IBM in the United States, working at the Thomas J. Watson Research Center in New York, the East Fishkill Development Laboratory, and corporate headquarters.

He then returned to Cambridge and set up a nanofabrication laboratory to extend the technology of miniaturization to the atomic scale. He also developed his research on using electrons, x-rays, and ultraviolet light in microscopy and on making microelectronic components. From 1996 to 2003 he was vice chancellor at the University of Cambridge, and in 1998 he was knighted for services to higher education.

Lord Broers has served on numerous national and international committees, including the Engineering and Physical Sciences Research Council, the Foresight Panel on Information Technology, the NATO Special Panel on Nanoscience, and the UK government's Council for Science and Technology. He is on the board of directors of Vodafone and RJ Mears LLC.

He was elected to the Royal Academy of Engineering in 1985, the Royal Society in 1986, and became a foreign associate of the US National Academy of Engineering in 1994. In 2004 Her Majesty the Queen made him a life Peer in recognition of his contribution to engineering and higher education. He was appointed chairman of the House of Lords Science and Technology Committee. In 2005 he presented the Reith Lectures for the BBC. In 2008 he became chairman of Diamond Light Source Ltd., the UK's largest new experimental scientific facility. In 2009 he became chairman of Bio Nano Consulting and in 2010 chairman of the Technology Strategy Board Knowledge Transfer Network for Transport. In 2012 he chaired the Judging Panel of the Queen Elizabeth Prize for Engineering.



Lord Broers received a first degree in physics from Melbourne University in 1959 and then went to the University of Cambridge, where he completed a degree in electrical sciences (after arriving initially as a choral scholar) and his PhD in 1965.

JOHN A. MONTGOMERY is director of research at the US Naval Research Laboratory, where he oversees research and development programs with expenditures of approximately $1.2 billion per year. He joined the NRL in 1968 as a research physicist in the Advanced Techniques Branch of the Electronic Warfare Division, where he conducted research on a wide range of electronic warfare topics. In 1980 he was selected to head the Off-Board Countermeasures Branch, and in 1985 he was named superintendent of the Tactical Electronic Warfare Division. He has been responsible for numerous systems developed/approved for operational use by the Navy and other services, and had great impact through the application of advanced technologies to solve unusual or severe operational deficiencies during world crises, most recently in Afghanistan, Iraq, as well as for Homeland Defense and in the Pacific Theater.

Dr. Montgomery received the Department of Defense Distinguished Civilian Service Award in 2001, the Department of the Navy Distinguished Civilian Service Award in 1999, the 1997 Dr. Arthur E. Bisson

Prize for Naval Technology Achievement in 1998, and the Department of the Navy Meritorious Civilian Service Award in 1986. Further, he received the Association of Old Crows (Electronic Defense Association) Joint Services Award in 1993. As a member of the senior executive service, he received the Presidential Rank Award of Distinguished Executive in 1991 and 2002, and the Presidential Rank Award of Meritorious Executive in 1988, 1999, and 2007. He was an NRL Edison Scholar and is a member of Sigma Xi. He was US national leader of the Technical Cooperation Program's multinational Group on Electronic Warfare from 1987 to 2002, and served as its executive chairman. He received the Laboratory Director of the Year award from the Federal Laboratory Consortium for Technology Transfer in 2006, and in 2011 the Roger W. Jones Award for Executive Leadership from American University's School of Public Affairs. He was elected to the National Academy of Engineering in 2013.

Dr. Montgomery received his BS degree in 1967 and MS in 1969 from North Texas State University and his PhD from the Catholic University of America in 1982, all in physics.

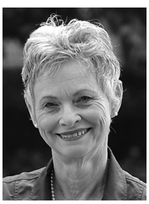
SUBRA SURESH became president of Carnegie Mellon University on July 1, 2013, after serving as director of the National Science Foundation, a position for which he was nominated by President Barack Obama and unanimously confirmed by the Senate in 2010. From 2007 to 2010 he was dean and Vannevar Bush Professor of Engineering at the Massachusetts Institute of Technology. His research into the properties of materials and discoveries of connections between cell properties and human diseases has shaped new fields in the fertile intersections of traditional disciplines. He has authored some 300 research articles, 21 patents, and three widely used books.

In his leadership roles at MIT and NSF, Dr. Suresh established initiatives to advance education, innovation, interdisciplinary research, diversity, and global collaboration. He was the founding chair of the governing board of the Global Research Council, a virtual organization established by leading funding agencies from nearly 50 developed and developing nations to harmonize and coordinate practices that enhance international collaboration.

Dr. Suresh is an elected member of the US National Academies of Sciences and Engineering, American Academy of Arts and Sciences, and academies in Germany, Italy, Sweden, Spain, and India. He has been awarded ten honorary doctorate degrees from universities in the United States, Sweden, Switzerland, Spain, China, and India. In 2011 the president of India awarded him the Padma Shri, one of the highest civilian honors, for his contributions to science and technology. In 2006 *Technology Review* magazine selected him as a top-ten researcher whose work "will have a significant impact on business, medicine, or culture." His other honors include the 2006 Acta Materialia Gold Medal, the 2007 European Materials Medal, the 2008 Eringen Medal of the Society of Engineering Science, the 2011 Nadai Medal and 2012 Timoshenko Medal from the American Society of Mechanical Engineers, and the 2013 Benjamin Franklin Medal in Mechanical Engineering and Materials Science from the Franklin Institute.

MARIE THURSBY is a Regents' Professor and holds the Hal and John Smith Chair in Entrepreneurship at the Scheller College of Business, Georgia Institute of Technology. She is also the Georgia Tech Social and Ethical Coordinator for the NSF National Nanotechnology Infrastructure Network, and has been a research associate of the National Bureau of Economic Research since 1987.

Dr. Thursby is the founding director of the nationally acclaimed program Technological Innovation: Generating Economic Returns



(TI:GER), a unique educational collaboration between Georgia Tech and Emory that teams PhD students in engineering and science with MBA and JD students in an experiential curriculum focused on the intersection of technical, legal, and business issues at the heart of innovation. Established in 2002 with an NSF Integrative Graduate Education in Research Training (IGERT) award, TI:GER has received the Award for Exceptional Activity in Entrepreneurship Across Disciplines from the Global Consortium of Entrepreneurship Centers, the Academy of Management Entrepreneurship Pedagogy Award, and the Model Specialty Entrepreneurship Program Award from the United States Association for Small Business Enterprise.

Dr. Thursby has published extensively on the economics of innovation, with emphasis on the role of universities in innovation systems, multinational R&D decisions, and the role of contracts in effective technology transfer. Her current research focuses on incentive problems in biomedical translational research and information sharing among competitive researchers.

Before joining Georgia Tech, Dr. Thursby held the Burton D. Morgan Chair of International Policy and Management at Purdue University, where she established three multidisciplinary programs: the Innovation Realization Lab (launched in 1998 with an NSF IGERT), the Alan and Mildred Peterson Technology Transfer Initiative, and the Purdue Center for International Business Education and Research. She held prior faculty appointments at the University of Michigan, Ohio State University, Syracuse University, and North Carolina State University.

She received her AB cum laude from Mount Holyoke College and her PhD from the University of North Carolina at Chapel Hill, both in economics.