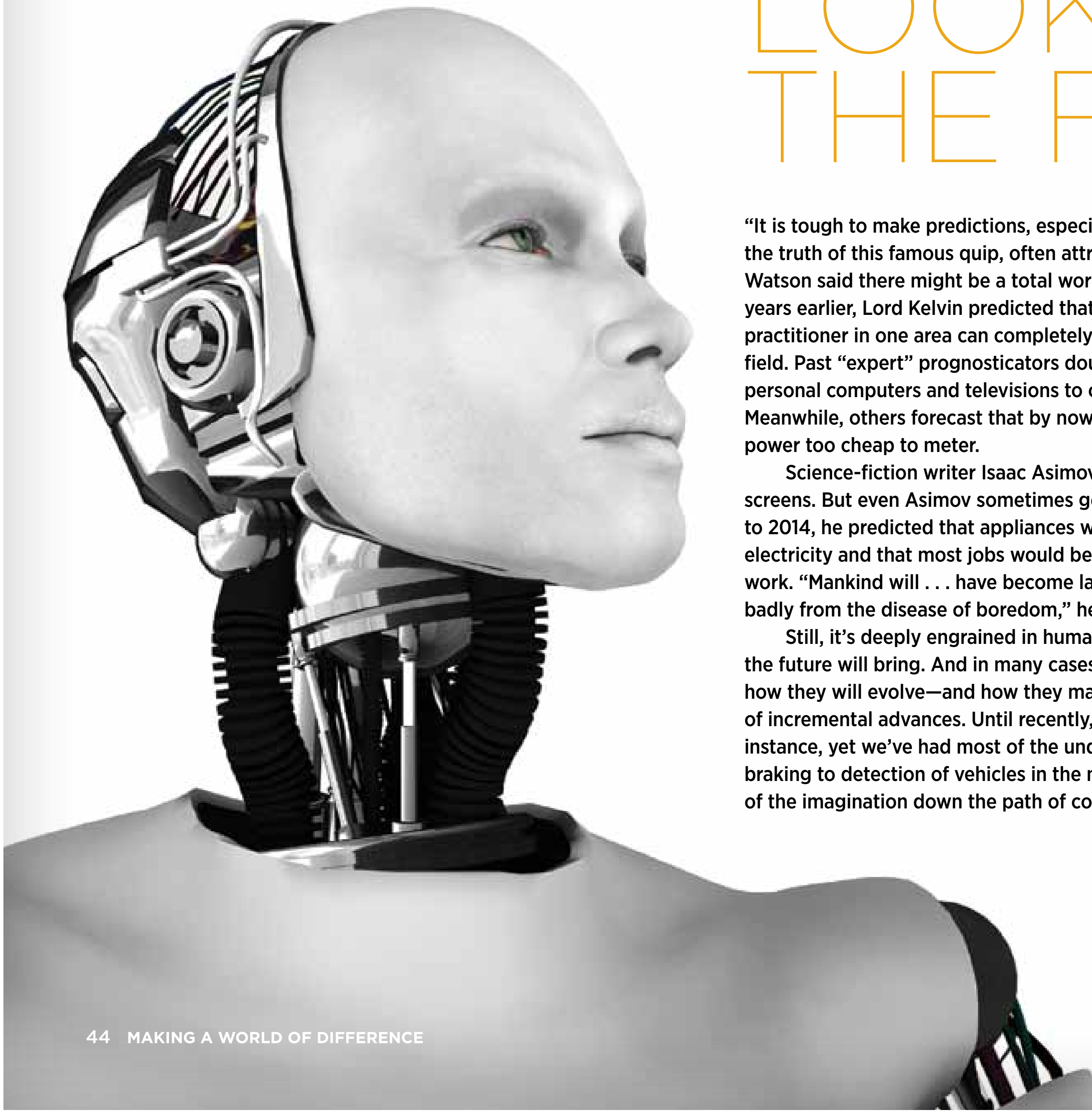


The Next 50 Years
LOOKING TO THE FUTURE

"It is tough to make predictions, especially about the future." Countless examples attest to the truth of this famous quip, often attributed to Yogi Berra. In 1943, IBM chairman Thomas Watson said there might be a total world market "for maybe five computers." Forty-four years earlier, Lord Kelvin predicted that "radio has no future," proving that a brilliant practitioner in one area can completely miss the significance of developments in a different field. Past "expert" prognosticators doubted the utility or appeal of everything from personal computers and televisions to online shopping and overnight package delivery. Meanwhile, others forecast that by now we'd have flying cars, colonies on Mars, and fusion power too cheap to meter.

Science-fiction writer Isaac Asimov correctly anticipated videophones and giant flat TV screens. But even Asimov sometimes got it wrong. In a 1964 essay looking ahead 50 years to 2014, he predicted that appliances would be powered by radioisotopes rather than electricity and that most jobs would be done by machines, freeing up people from actual work. "Mankind will . . . have become largely a race of machine tenders . . . [and] will suffer badly from the disease of boredom," he wrote.

Still, it's deeply engrained in human nature to gaze into a crystal ball and imagine what the future will bring. And in many cases, we can look at today's technologies and anticipate how they will evolve—and how they may bring surprising changes that emerge from a series of incremental advances. Until recently, driverless cars seemed like a distant dream, for instance, yet we've had most of the underlying technologies—from computer-controlled braking to detection of vehicles in the next lane—for years. So it's worth taking a journey of the imagination down the path of continued development of today's technologies.

Brought to You by Engineering

Over the next half century, we can foresee tackling—and solving—many of the pressing problems facing humanity and society today. An NAE report in 2008 describes 14 Grand Challenges for Engineering, such as creating better medicines, restoring and improving our cities, and providing more sustainable sources of energy. Yet even as some of these challenges are met, new issues will arise, sometimes in the form of adverse unintended consequences of our successes. In every case, engineering will be critical to the solution.

Perhaps most important, though, while our imaginations may be spot-on in some cases, in many others the future will be far different than what we now foresee. It will bring answers to questions we aren't asking, and solutions to needs we don't know we have. It will enrich and enhance human lives in ways that are simply impossible to predict—surprising and delighting us, and creating innovations that soon will seem impossible to live without. Mobile phones, for example, were a staple of science fiction and a goal of engineers for years, but the first clunky models were something of a hard sell, and we certainly didn't know we needed smartphones—or social media—until suddenly we did. Today's youth find it hard to believe that previous generations could function without these inventions.

Whatever the shape of the future, the underpinnings and most of the details will come from engineering innovations. As computer scientist Alan Kay, president of the Viewpoints Research Institute once said, "The best way to predict the future is to invent it"—and that's precisely what engineering does.

Grand Challenges

Foremost among the challenges are those that must be met to ensure the future itself.

In 2007 NAE at the request of NSF, convened a diverse international panel of some of the most accomplished engineers and scientists of their generation. The panel's task: to consider broad realms of human concern—sustainability, health, vulnerability, and joy of living—and propose a set of the challenges most in need of 21st-century engineering solutions.

The panel did not attempt to include every important goal for engineering. Rather, it chose the problems we must solve to ensure survival of a livable Earth and the well-being of its inhabitants. Earth's resources are finite, and our growing population currently consumes them at a rate that cannot be sustained. Among the most pressing concerns, then, is the need to develop new sources of energy while also preventing or reversing the degradation of the environment. Another is to find new methods to protect people against pandemic diseases, terrorist violence, and natural disasters. The engineering solutions to challenges such as these can no longer be designed solely for isolated locales, but must address Earth as a whole and all the planet's people. As the panel concluded in its 2008 report, "a world divided by wealth and poverty, health and sickness, food and hunger, cannot long remain a stable place for civilization to thrive."

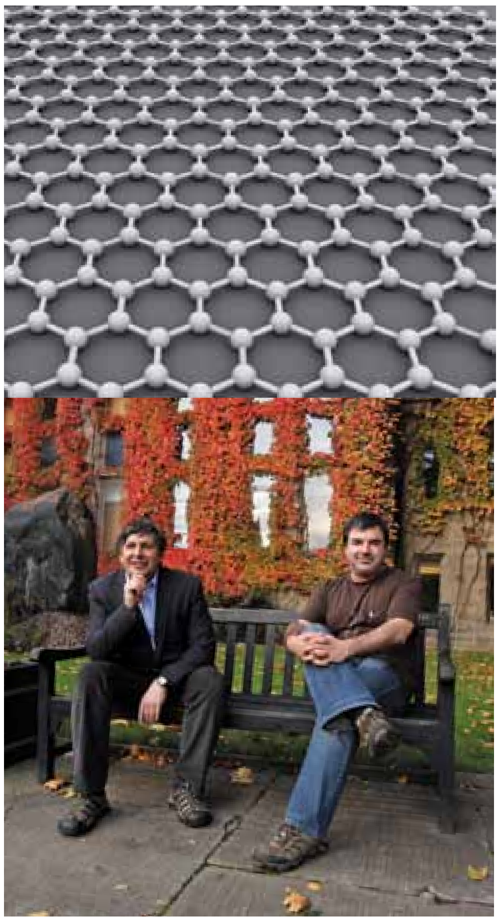
- **Make solar energy economical**
- **Provide energy from fusion**
- **Develop carbon sequestration methods**
- **Manage the nitrogen cycle**
- **Provide access to clean water**
- **Restore and improve urban infrastructure**
- **Advance health informatics**
- **Engineer better medicines**
- **Reverse-engineer the brain**
- **Prevent nuclear terror**
- **Secure cyberspace**
- **Enhance virtual reality**
- **Advance personalized learning**
- **Engineer the tools of scientific discovery**

To learn about the Grand Challenges for Engineering visit the project's interactive website at **www.engineeringchallenges.org**

New Materials, New Possibilities

From the Stone Age to the Iron Age, epochs of human history have been named after materials. That's not surprising, because new materials open the door to entirely new and unexpected applications and developments, weaving new threads into the tapestry of human progress and changing how we live and work. Today's Information Age might justly be called the "Silicon Age" because of the enormous capabilities provided by silicon-based devices and applications, although modern advances have also required numerous other crucial materials, from optical fibers to high-strength alloys. The silicon frontier will be extended farther, no doubt, but new materials may take us beyond a simple extrapolation of today's technology, meeting the needs that we don't yet know we have.

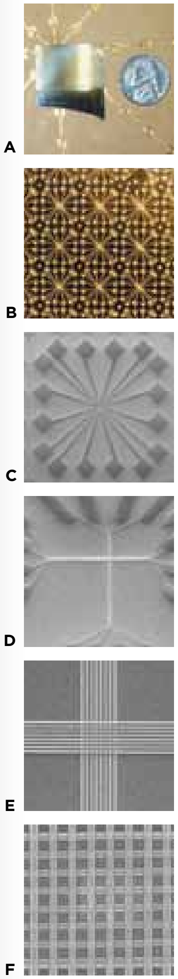
A new material—graphene—is a layer of carbon only one atom thick, discovered by physicists Andre Geim *(bottom, left)* and Konstantin Novoselov, who won the 2010 Nobel Prize in Physics for their groundbreaking experiments.



Scientists and engineers are now hard at work creating and exploring the potential of new materials. In the early 2000s, for example, physicists Andre Geim and Konstantin Novoselov at the University of Manchester in England were tinkering with graphite and tape. They realized that it was possible to peel off a layer of carbon so thin that it was only one atom thick. This material, dubbed graphene, was almost completely transparent, yet so dense not even helium could pass through. Possessed of immense strength, it also had interesting electrical properties, which Geim and Novoselov nailed down by studying dozens of ultrathin electronic devices they made from graphene. Their work won them the 2010 Nobel Prize in Physics—and pointed to a new path for devices. "Graphene could change the electronics industry, ushering in flexible devices, supercharged quantum computers, electronic clothing and computers that can interface with the cells in your body," predicted the *New York Times* in 2014.

Meanwhile, in Hewlett Packard's Quantum Science Research Lab, Stanley Williams has built novel devices with a completely different approach. His idea: Use chemical reactions to grow switches and wires that assemble themselves into circuits. Working with colleagues at UCLA, Williams fashioned the world's first molecular logic gate, the building block of digital circuits. If such "molecular electronics" devices could be used to create viable computers, they could put the power of a hundred workstations on a chip the size of a grain of sand.

We don't know if the central processors of computers 25 or 50 years from now will be built from graphene, self-assembled molecules, DNA, or any of a number of other exotic materials emerging from today's laboratories. We do know, however, that the enormous advances in materials (and concomitant leaps in computing power) that have already transformed our lives in 2014 will continue—perhaps even accelerate. Engineers will create ever-smaller devices, exploiting the strange world of quantum mechanics, where atoms can exist in different places at once and affect each other across considerable distances. "Materials with genuine quantum properties will have enormous impact," says Venkatesh Narayanamurti, professor of technology and public policy at Harvard University's School of Engineering and Applied Sciences. And other improved or new materials will enable continual advances in everything from cars and planes to the buildings we live in.



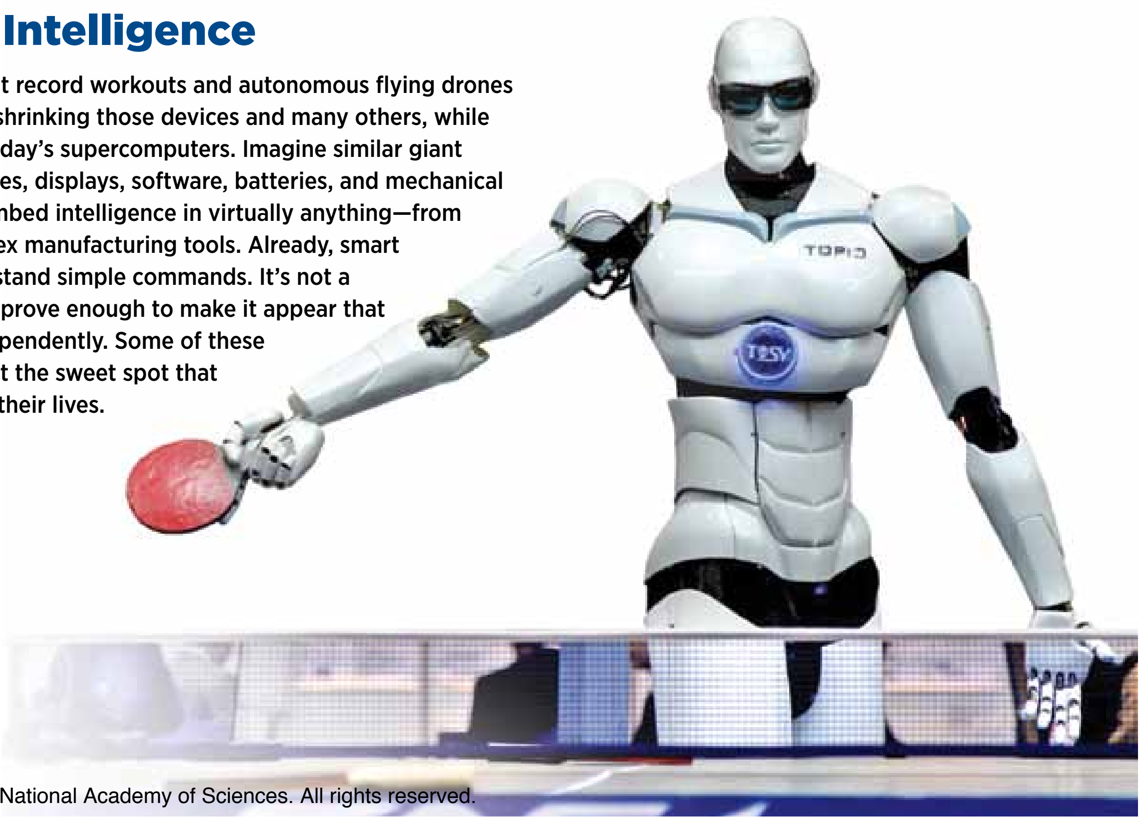
A B C D E F

In this series from HP Labs, each successive image is magnified about 10 times the previous one, from (A), the wafer on which 625 64-bit memories are imprinted, through (F) a close-up of a single memory, with one bit stored at each of the 64 intersections.

The future is now: Flying drones that deliver packages and cars that drive themselves are already being tested, while virtual reality software helps train aviators both to fly a plane and to jump out of it.

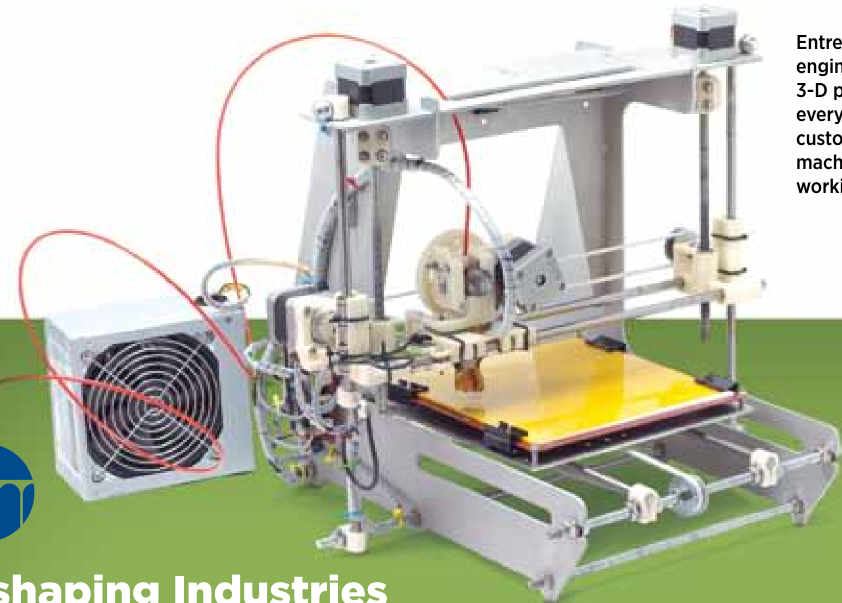
A World of Embedded Intelligence

In 2014, we already have sports watches that record workouts and autonomous flying drones the size of birds. But imagine dramatically shrinking those devices and many others, while also adding the raw computing power of today's supercomputers. Imagine similar giant leaps in sensors, communications capabilities, displays, software, batteries, and mechanical actuators. Put all those together and we can embed intelligence in virtually anything—from light bulbs and refrigerators to cars and complex manufacturing tools. Already, smart devices can answer simple inquiries and understand simple commands. It's not a stretch to predict that these capabilities will improve enough to make it appear that devices are thinking, speaking, and acting independently. Some of these devices will fail in the market, but others will hit the sweet spot that delights consumers and improves or enhances their lives.



Here's just a sample of what may be possible, some of which is already taking shape: Virtual reality technology that trains the military. Cars that drive themselves, in constant communication with other vehicles and with traffic signals. Appliances and houses that respond to voice commands—maybe even know what you want automatically. Displays that cover entire walls, enabling us to put an art gallery with treasures like the *Girl with a Pearl Earring* in our homes, visit with grandma in what feels like an adjacent room, negotiate a deal across the "table" with partners in Tokyo or Kazakhstan, have a prime seat at the opera or rock concert, work with a personal trainer, or take a virtual climb up Mount Kilimanjaro. One of the NAE's Grand Challenges, enhancing virtual reality, will be easily met, predicts Ray Kurzweil, now tackling natural language understanding at Google. "By the early 2020s we will be routinely working and playing with each other in full immersion visual-auditory virtual environments," he writes. Another Grand Challenge, tailoring education to meet individual needs, will also be met, says Leah H. Jamieson, dean of engineering at Purdue University. "I absolutely believe it will be possible to build interactive systems that provide personalized learning environments."

The future world could bring what Asimov anticipated a bit too early—the creation of robots that read, learn, and even feel. Such robots could take care of the elderly, file tax returns, build houses, and discuss the origins of the universe or the latest escapade of the next generation of reality TV stars. "We will have another intelligent species on Earth," predicts Danny Hillis, chairman and cofounder of Applied Minds, LLC.



Entrepreneurs and engineers are using 3-D printers to create everything from custom toys and machine parts to working prostheses.

Reshaping Industries

New materials are one driver of change. Development of new manufacturing methods and tools is also crucial—another job for engineers. Consider 3-D printing. GE Aviation used to make jet engine nozzles by welding together 18 different parts. But not for its latest, most efficient engine. The company now builds the nozzles one layer at a time by precisely depositing material with a 3-D printer, in much the same way an ink-jet printer sprays on paper.

3-D printing is a potential game changer for today's factories, warehouses, supply chains, distribution systems, and delivery companies. It also has the potential to eliminate the waste of raw materials in manufacturing processes. Instead of machining or forging a part like a connecting rod, a 3-D printer puts material just where it's needed, like an oyster building up its shell layer by layer. "3-D printing sounds trite, but you can build structures that you could never do any other way," says Paul Citron, retired vice president for technology policy at medical device maker Medtronic. This technology makes it possible for anyone to become a manufacturer. "Imagine that instead of having to stock parts at an auto supply store, the guy goes to a keyboard when you ask for a part. He then makes the part at his 3-D printer and hands it to you," says John Wall, vice president and chief technical officer at engine and power systems manufacturer Cummins. Or imagine inventors dropping by the local 3-D print shop to print out working prototypes of their latest ideas. You could even print stuff in your own home.

It's also theoretically possible, if you have the right materials, to print almost anything, including living tissue. If you needed a new liver, say, doctors might extract a few of your stem cells, transform them into liver cells and print out your new organ. "By the early 2020s we will print out a significant fraction of the products we use, including clothing as well as replacement organs," predicts Google's Kurzweil.

Born without an arm, six-year-old Alex Pring of Groveland, Florida, practices picking up objects with his new 3-D printed prosthetic arm and hand, designed and made by engineering students at the University of Central Florida for about $350.

GE Aviation's new jet engine *(left)* includes a fuel nozzle made by 3-D printer.

Expanding Our Connections

Many visionaries foresee that people in future decades will want to be connected even more than they are today, and that such connections will improve their quality of life. If so, engineers will be the architects of this hyperconnected future. "The connectivity of everything is within a decade," predicts Charles Holliday, Jr., former CEO of du Pont. "It will change how we think about managing our lives." And by 2025, "information sharing over the Internet will be so effortlessly interwoven into daily life that it will become invisible, flowing like electricity, often through machine intermediaries," according to a 2014 report from the Pew Research Center's Internet Project. The developing world will continue to leapfrog the old wired infrastructure, as remote villages connect to the larger world with wireless broadband networks.

As is frequently the case with new technologies, hyperconnectivity will offer challenges along with opportunities. Will the regulations written for telephone communications need to be rewritten for the Broadband Age? Can cybersecurity efforts not only keep the hackers at bay but also keep criminals and terrorists in check? Can we find a balance between hyperconnection and personal privacy that is acceptable to most people? Governments and societies will need to grapple with these questions and challenges, but engineering advances will underpin the solutions.

Making Energy Sustainable

ntelligent, hyperconnected devices, 3-D printers, and other technologies will bring surprises, meet unanticipated needs, and change our lives in ways that are hard to imagine. But some aspects of the future are easier to predict. To create a better, richer, and healthier future for all people and nations, we know we must tackle and solve problems that are already obvious now.

J. Craig Venter *(far left)* is working on synthesizing algae to replace fossil fuels. In France an experimental thermonuclear reactor project is under construction *(above).*

One of those big challenges is creating a sustainable supply of energy. Energy is crucial to maintaining and boosting standards of living. To bring billions of people out of poverty, therefore, we'll either need more energy or huge improvements in energy efficiency—or, most likely, both. But right now, because of our dependence on fossil fuels, humans are emitting carbon dioxide and other greenhouse gases into the atmosphere at a rate that exceeds anything the Earth has experienced in millions of years. Since 1900, the planet has warmed by about 0.8 degree Celsius (1.5 degrees Fahrenheit), and the number of extreme weather events scientists are linking to warming has increased in recent years. There's "compelling evidence that increasing temperatures are affecting both ecosystems and human society," warns the 2014 National Climate Assessment.

Thus, the energy mix is as important as—or more important than—the total energy needed. If we want to avoid contributing to the carbon dioxide buildup by burning fossil fuels, efforts both to switch to renewable or other low-carbon power and to use less energy must go forward. Wind power and solar power currently represent about 7 percent of overall generating capacity, and engineering advances there and elsewhere are in the offing. Improvements in wind turbines and solar panels, for example, are rapidly making them more efficient and cheaper, and new battery technologies promise to solve the problem of intermittency. Argonne National Laboratory, for instance, is leading a major multi-institution effort to build a battery with five times the energy density of today's best, at one-fifth the cost. Such batteries could also make electric cars far more practical and attractive, weaning much of the transportation sector from the fossil fuel pump.

Huge improvements are possible in using energy more efficiently. Something as simple as better insulation, such as ultralight aerogels, can dramatically reduce the energy needed to heat and cool homes and factories and run refrigerators.

Engineers are also working to design safer, cheaper nuclear reactors. As a virtually carbon-free source of reliable energy, "nuclear power has to play a significant role in the future," says Cummins's John Wall. It may also be possible to harness the fusion reaction that powers the sun—another NAE Grand Challenge. A research reactor, the International Thermonuclear Experimental Reactor Project, is now under construction in Cadarache, France. Although fusion energy still faces daunting technical hurdles, many experts remain hopeful. "I think we'll have fusion, maybe not in 50 years, but eventually," says Julia Phillips, vice president and chief technology officer at Sandia National Laboratories.

Meanwhile, other creative ideas abound. For example, Caltech's Frances Arnold, winner of the 2011 Draper Prize, is using the techniques of directed evolution to produce new biocatalysts to convert cellulose to sugars and then to biofuels. In other labs researchers use catalysts and other materials to mimic photosynthesis and capture energy from sunlight. At least five different designs are competing to turn the energy from ocean waves or tides into electricity. Smart micro-grids promise not only to keep the lights on in U.S. cities, but also to bring renewable power to remote villages in developing countries, bypassing the need for expensive power lines and central power plants.

Some visionaries believe human ingenuity and engineering wizardry can easily wean humanity from fossil fuels within 50 years. Kurzweil, for one, predicts that "by 2030 solar energy will have the capacity to meet all of our energy needs"—including providing enough extra power to purify vast amounts of salty water. Meeting the Grand Challenge of making solar energy economical thus could also satisfy the growing need for clean water, another Grand Challenge. A surplus of energy would also make it possible to power scrubbers that can pull carbon dioxide and all other forms of pollution from the air, says Cherry Murray, dean of Harvard University's School of Engineering and Applied Sciences.

The conventional wisdom, though, is that wind and solar alone can't provide enough energy for a growing world, especially when the wind dies or the sun sets. Many experts insist that the world will depend on fossil fuels for a sizeable percentage of its energy for a least 50 more years. "Energy is going to come from a lot of different sources," says Holliday. In particular, if for no other reason than it is plentiful and cheap, the world is unlikely to stop burning coal soon, with 2,300 existing coal plants and more than 1,000 proposed new facilities. So, to reduce emissions in the medium term, even for the long-term, wide-scale implementation of improved technologies for grabbing the carbon from fuel or carbon dioxide from smokestacks is essential. And additional innovations are needed to pave the way for safe storage of that carbon, meeting the Grand Challenge of developing carbon sequestration methods.

Creating a cleaner, more sustainable energy future will require hard decisions based on data and evidence, which can come from engineering advances such as more powerful supercomputers and sophisticated sensors on land, in the oceans, and in space. The decisions themselves are typically outside the realm of engineers and scientists—but scientists and engineers will need to engage them as they work to create solutions to the world's energy problems. As a practical matter, according to the National Climate Assessment and a joint report by the U.S. National Academy of Sciences and the Royal Society in the United Kingdom, carbon dioxide concentrations and global temperatures presently in place make some climate impacts inevitable, even if greenhouse gas emissions were to cease. So, as we hedge our bets by striving to change the energy mix, engineers also face the challenge of helping society adapt to the changing global environment.

Feeding the World's Billions

The combination of massive harvesters and other farm machinery, precision fertilization, genetically modified crops, and other advances has dramatically boosted yields of corn and other crops across the United States and around the world. At the dawn of the 20th century, about 50 percent of the U.S. population was involved in food production. Today that number has dropped to 2 percent.

But to feed the world's growing number of people, we will need another increase in productivity. One of many possible answers to this problem is harnessing the potential of genetic engineering and fermentation. Biological engineers are already growing gene-spliced algae that make a full set of the protein building blocks, or amino acids, that we need in our diet. Turn that algae into flour, and we could replace millions of acres of amber waves

"We'll have local food in home gardens, hanging gardens, and hydroponic gardens in all sorts of interesting places."

of grain with giant stainless steel vats filled with fermenting microbes. Slip in the genes for muscle and blood proteins like actin and myogloblin, along with genes for healthful fats, and algae or other microbes could even make what J. Craig Venter, chairman and president of the J. Craig Venter Institute, dubs "motherless meat," ending the need for a home on the range.

Venter calculates that microbial factories could produce as much food as our current system of agriculture using only one-tenth the land area. If we wanted, we could turn the Great Plains back into a vast prairie teeming with buffalo, or bring forests back to many areas of the world that were cleared for cultivation. Plus, the approach would solve one of NAE's Grand Challenge problems—managing the nitrogen cycle to reduce the nutrient pollution that's harming the world's creeks, rivers, lakes, and coastal areas.

Of course, that's just one possibility. Harvard's Murray and others have different ideas for feeding the world's billions of people. Murray predicts that a global disaster—such as a disease that wipes out all wheat or rice crops—will bring a dramatic shift from today's industrial monoculture agriculture to a distributed, local system, where a wide range of plants are grown on rooftops and other spaces throughout cities and communities. "We'll have local food in home gardens, hanging gardens, and hydroponic gardens in all sorts of interesting places," she says. In fact, this trend toward more local food is already beginning—even without a major crop failure.

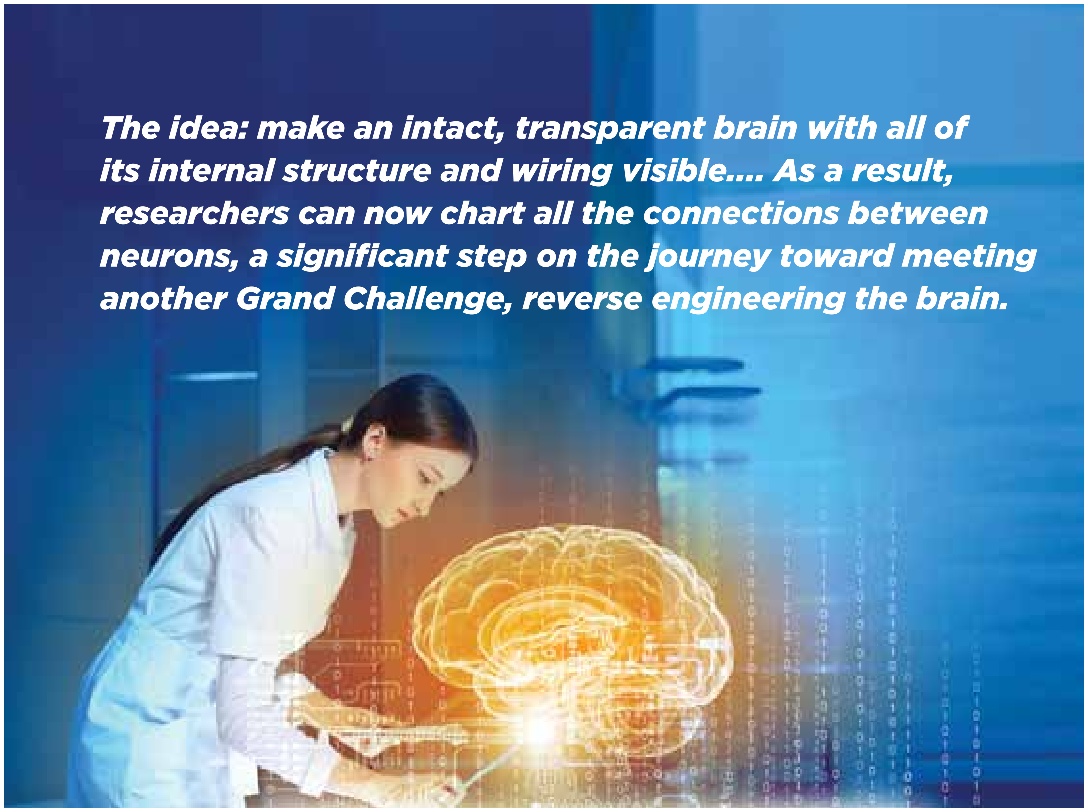
A Healthier Future

Among the many medical advances from the lab of MIT chemical and biomedical engineer Robert Langer are polymers designed to dissolve at different rates in the bloodstream. Encapsulate a drug or a vaccine inside tiny spheres made from these materials, inject them into the blood, and the microspheres will "deliver" the actual medicines to the site of cancers or other tumors days or weeks later. "It may sound trivial, but it can help change the face of medicine," says Langer.

To fight deadly diseases such as tuberculosis or Ebola, doctors must treat people with multiple, periodic doses of drugs or vaccines. Yet in many parts of the world, it's hard enough to get patients to health clinics once, let alone every few weeks. Microsphere technology solves that problem. Patients could be given full courses of treatment or vaccinations with a single injection. Suddenly, once-intractable diseases can be cured or prevented.

Over the next few decades, bioengineers are expected to create many more such weapons in the fight against infectious diseases. These innovations might include malaria and tuberculosis vaccines as well as cheap, effective (and simple to administer) drugs against HIV, and robust technologies for delivering clean water and providing basic sanitation in underdeveloped countries. By 1980 the world had eradicated smallpox. It's not a great leap of imagination to think that we can finish the job of eliminating polio and make dramatic inroads against cholera, AIDS, diphtheria, and other terrible infectious diseases. The benefits would be enormous, not just in reducing infant mortality and increasing life expectancy, but also in boosting productivity, economic growth, and standards of living all over the world.

But that's just the beginning of how science and engineering have the potential to transform health. Drop in, for instance, at the Stanford lab of Karl Deisseroth, which recently tackled a project so



The idea: make an intact, transparent brain with all of its internal structure and wiring visible.... As a result, researchers can now chart all the connections between neurons, a significant step on the journey toward meeting another Grand Challenge, reverse engineering the brain.

risky that Deisseroth enlisted only those colleagues whose careers were sufficiently established that they would not be set back by a failure. The idea: make an intact, transparent brain with all of its internal structure and wiring visible. The team succeeded, figuring out how to support a mouse brain with an external hydrogel skeleton, then dissolving away its opaque fat. As a result, researchers can now chart all the connections between neurons, a significant step on the journey toward meeting another Grand Challenge, reverse engineering the brain.

Eventually, with better understanding of brain chemistry as well as brain circuitry and the underlying mechanisms of biology and disease, medical professionals may be able to intervene successfully in everything from addiction and epilepsy to schizophrenia and Parkinson's disease. Meanwhile, researchers predict that advances in understanding the biology of the rest of the body will make it possible to tame autoimmune diseases and cancer.

Similar gains will come from reading humanity's genetic code, from cataloging all of our proteins, and from manipulating genes and biology. Danny Hillis of Applied Minds foresees making real-time measurements of the chemicals coursing through the body, and then using computing tools like data mining and pattern recognition to spot chemical signals going awry—long before any actual symptoms of illnesses appear. "We'll be able to see a problem coming and intervene on the side of the body before we ever get sick," he predicts. Paul Citron, retired from Medtronic, expects that for diabetics "an artificial pancreas will become a reality," staving off the many complications of diabetes by precisely controlling blood sugar. MIT's Langer—who was awarded the 2002 Draper Prize for "bioengineering of revolutionary medical drug delivery systems"—predicts that it will be possible to regenerate spinal cords, to replace failing organs and body parts with engineered tissue and to turn the body into its own drug factory by injecting the manufacturing instructions in the form of messenger RNA. "The combination of biology and engineering will lead to all kinds of new things, improving the quality of care and quality of life," he says.

Just as with computer power and the connected world, these advances could be of tremendous benefit to humanity. We'll get longer, healthier, more productive lives—and, with advances in brain science, a deeper understanding of what it means to be human.

But the technology will also raise difficult questions and ethical dilemmas. Will society be willing (and able) to pay for expensive new treatments and approaches for everyone, or will these advances benefit only the rich? Once it becomes possible, will we rush to tinker with our genes to create new generations with superior athletic abilities or intelligence? It could indeed be a brave new world. "Human engineering will be inevitable," says J. Craig Venter. Once again, how tomorrow's society decides to use its new engineering powers will be crucial.

China alone must build the equivalent of a city the size of Boston every 17 days to accommodate the 14 million additional people per year projected to live in the country's urban areas.

Cities, Limits, and New Frontiers

A half century from now, one of the most critical factors determining what the future looks like will be this: how many people will be packed onto the planet? The United Nations' best estimate is that the global population will climb from today's 7.2 billion to 9.6 billion in 2050. But higher fertility could send that soaring past 15 billion by the end of the century. Or if the developing world emulates the low birth rates of countries like Italy and Japan, the number could actually decline by then to 7 billion.

Either way, the consequences will be profound. A more populated world increases the challenges of providing food, health care, and housing—even bumping up against the limits of what the planet can support. On the other hand, lower population numbers mean that average age will climb quickly, making it harder to care for the elderly. The number of people older than 65 is on track to exceed those younger than 15 in most countries within a decade or two—for the first time in human history.

One trend that's safe to predict, however, is increasing urbanization. More than half the world's people now live in cites. A million more are born there or move in every week. China alone must build the equivalent of a city the size of Boston every 17 days to accommodate the 14 million additional people per year projected to live in the country's urban areas. How can we keep all these people from ending up in sprawling shantytowns all over the world?

Many urban planners suggest that the answer lies in taller, denser cities. According to Antony Wood, executive director of the Council on Tall Buildings and Urban Habitat, engineers already know how to build soaring structures two or three kilometers tall. What's harder is maintaining the vitality of urban life in a city of super-skyscrapers. So much of the vibrancy of a city goes on at ground level—in parks, shops, and restaurants. The answer may be to bring that vitality upward. "If a city gets ten times more vertical and ten times denser, then we need to replicate the ground level in the sky—creating urban habitats in the sky," says Wood. That shift would be a major undertaking for urban planners and civil engineers.

Of course, future cities won't be able to function without other vital engineering advances: replacing and redesigning aging water mains and sewers; reshaping transportation systems to cope with higher populations. In the United States, urban engineers can envision a future where the number of cars drops and an increasing proportion are shared. When not in use in the denser, future city, many cars might sit around in automated multistory garages. Need a car? Call one with your smartphone. It may even drive to you and chauffeur you around. When you're done, "push a button and the car parks itself in the parking garage," says Holliday. Urban planners and engineers are already exploring many of these possibilities.

With more than 40 percent of the world's population living within 60 miles of coastlines—and many more along rivers—engineers must also figure out how to make cities more resilient against rising seas, river floods, and extreme weather events. In the aftermath of 2012's Superstorm Sandy, for instance, New York City has developed a detailed plan for reducing the damage from future storms. The engineering steps that New York and other cities could take are as simple as elevating homes and moving the mechanical guts of buildings from the basement to higher floors, or as complex as re-creating and reengineering the buffer of coastal wetlands that can protect cities from raging storm surges.

But engineering the path to the future is not just about planning for disaster, coping with potential limits, or finding solutions to innumerable problems. As this chapter tries to convey, it's also about eradicating diseases; lifting millions out of poverty and sickness; forging stronger, more resilient communities; and preparing for many possible futures. It's about making life richer and more fulfilling. It's about pushing back the frontiers of knowledge—even freeing us from the bounds of Earth. "Within 25 years, we'll go to space as routinely as we go the grocery store today," predicts Wanda Austin, president and CEO of The Aerospace Corporation. "It could be for fun or because it's critical for our survival."

Just imagine what it would mean to use engineering advances to finally understand the mysterious dark matter that makes up most of the universe or to discover extraterrestrial life. "Contributions from engineering will bring many more astonishing insights about ourselves, our Earth, and our universe in the next 50 years," says Princeton University's Robert Socolow.

Decade by decade, century by century, engineering has taken us further and further from the first glimmerings of human art and culture on the walls of Paleolithic caves. And to some experts, it's even helping us leave behind some of the darker side of human nature. Harvard University cognitive scientist Steven Pinker argues that as human society becomes more modern (in large part from technological advances), we become a kinder, gentler species. "You can see [the decline of violence] over millennia, over centuries, over decades, and over years," he says. "We are probably living in the most peaceful time in our species' existence."

It's a highly controversial idea, but a hopeful and attractive one. If the march toward greater enlightenment continues—and the flowers of engineering bloom as they have throughout history—then the next half century really will be worth looking forward to.

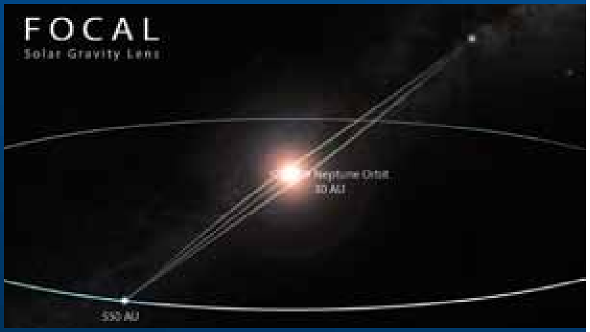
VIEW FROM AFAR

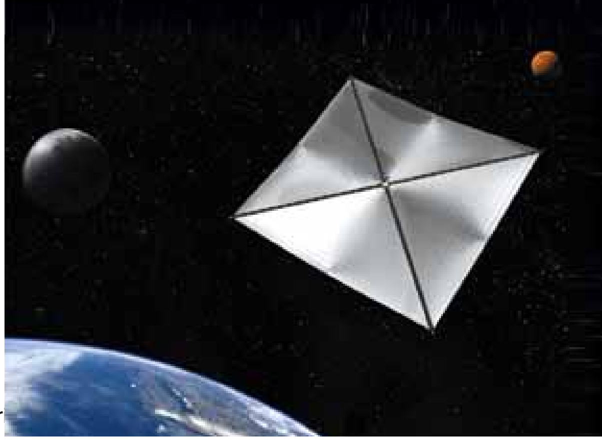
A First Step to Other Planetary Systems

The Kepler Space Telescope, launched in 2009 to search for planets orbiting other stars, has found many such systems, including at least one, Kepler-186, with a planet similar to Earth in what astronomers call the "habitable zone"—the distance from a star at which liquid water can exist. Kepler-186 is 500 light-years away, meaning that light from its star takes 500 years to reach us. With the technology of the next decade or two, 500 light-years is much farther than we can send a probe to do a flyby.

But we can undertake missions in the next few decades that could let us look more closely at some of the planets Kepler has found. Scientists and engineers have proposed to do this by taking advantage of an effect first predicted by Albert Einstein in 1936—namely, that the gravity of large objects would bend light, just as a glass lens does in a traditional telescope. Astronomers already use gravitational lensing to get better images, from our perspective on Earth, of objects located beyond large stars or galaxies. However, they can't "aim" a galaxy or re-position Earth to choose what to examine.

We could use our Sun itself as a gravitational lens—except we can't do it from Earth, or even from Earth orbit; we're much too close. Instead, we have to send a telescope out along the focal axis of the solar lens—to the closest point where the light from the object we want to look at, bending around the Sun, comes into focus *(above)*. The trick is getting our telescope out there. The focus of the solar lens begins 3.2 light-days from the Sun and continues outward, with the image quality improving as the telescope gets farther away from the Sun.





Over the next half century, engineers will develop new probes that will be smaller, lower mass, and easier to propel to high speeds than anything we've launched so far. They will be powered by new propulsion systems, such as ion rockets or "light sails" ***(below left)*** that catch the solar wind speeding from the Sun at more than million miles per hour. With a push from a laser beamed from Earth, our telescope's light sail could reach the focus of the solar lens in a few years. As engineering advances make probes still smaller and less expensive, we could even launch a swarm of space telescopes to different focal points of the Sun's gravitational lens, giving us close-ups of more distant stars and the means to detect radio or optical signals that might indicate an advanced civilization.

"The new frontier of the 20th century was our solar system" says David Messerschmitt, Roger Strauch Professor Emeritus of Electrical Engineering and Computer Sciences, University of California, Berkeley. "And the new frontier for the 21st century will be interstellar space in our region of the Milky Way galaxy."