2014 A Healthier, Cleaner, More Connected World

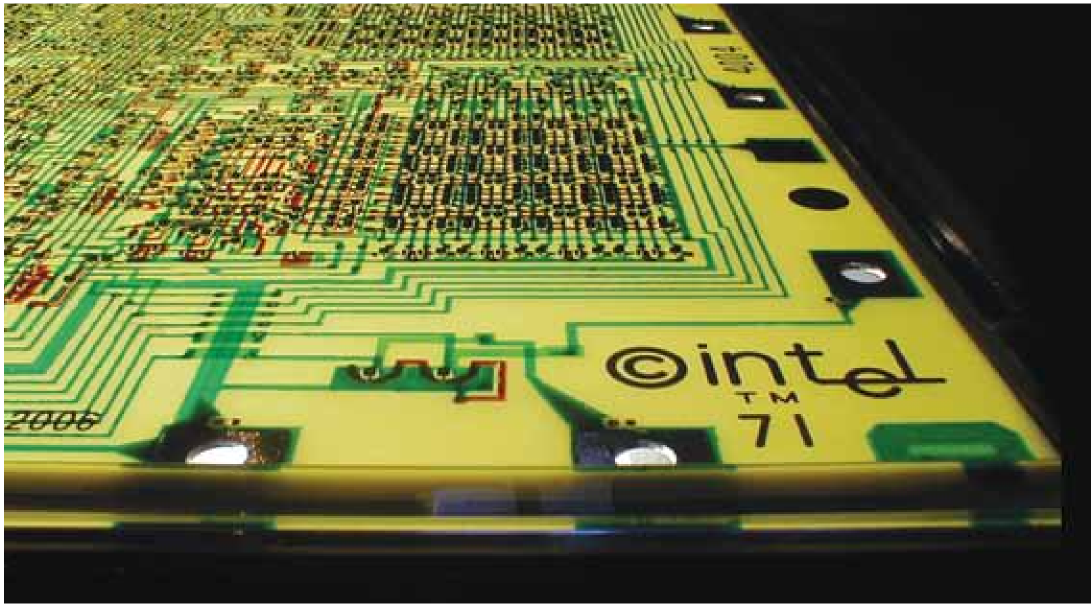
Surrounded by the fruits of innovation, we easily forget that much of what we now take for granted in 2014 was almost unimaginable 25 years ago. Back in the 1980s, pagers, e-mail, and floppy disks were cutting-edge technologies. Today we have smartphones, flash drives, and "the cloud." Back then the idea for the World Wide Web was just beginning to germinate in the mind of Tim Berners-Lee. Today roughly 40 percent of the world's population uses it, each of us for our own purposes. We go to the Web to learn and to share, to buy and sell, to meet new people and locate old friends, to check the weather, pay bills, and renew the car registration. And the more we use it, the more it evolves to meet our needs.

Technological advances made over just a few decades are boosting economies, feeding the hungry, and healing the sick. Iowa farmers achieve record yields with gene-spliced crops and other agricultural technologies. New vaccines hold out the promise for tackling scourges like malaria and some cancers, while doctors save lives by replacing diseased heart valves—in some cases without open-heart surgery. And who would have thought that in 2014 simple robots would vacuum our houses, highly complex ones would assist surgeons in performing lifesaving surgery, and cars would automatically slam on the brakes when a child darts out in front of them?

All these advances have come through engineering carried out in companies, universities, and national laboratories. Those efforts have created new materials like nanotubes and high-strength alloys, manufacturing technologies like 3-D printing, software and algorithms for harnessing the power of supercomputers and mining vast stores of data, and countless other innovations.

Yet these examples barely scratch the surface of the remarkable changes wrought over the last quarter century. Our lives, our workplaces, our societies have been transformed by an extraordinary flowering of engineering innovations. Life offers more possibilities, more richness, than ever before.

Wind turbines offer a clean, renewable source of energy.



Introduced in 1971, the Intel 4004 microprocessor *(left)* contained 2,300 transistors. The exponential increase in transistor counts *(see chart opposite page)* on tinier and tinier chips has led to such modern devices as digital cameras that can capture a breaking wave in mid-air.

Tiny Powerhouses, Global Reach

By the early 1980s, the semiconductor revolution was well under way. In 1982, engineers were packing 134,000 transistors on a single microprocessor chip, making the personal computer possible. In 1985, that number jumped to 275,000. But the chip designers began to run into a physical limit on the number of transistors on a chip. As the transistors got smaller and smaller, the width of each individual component in a chip design began to approach the wavelength of the visible light being used to transfer the design onto a silicon crystal wafer in a process called photolithography. As a result, the features—the transistors and connecting wires—weren't printed precisely enough to operate reliably. The features would get fuzzy, instead of being sharply delineated, allowing short circuits and causing the chips to fail.

The solution, IBM electrical engineer Kanti Jain realized, was a lithography tool that used shorter wavelength deep ultraviolet light instead of visible light. Jain and his team tapped into a device invented by Russian engineers in 1970s—the excimer laser, which creates ultraviolet light with electrical stimulation and high pressure on gas combinations such as krypton and fluorine. But the prevailing wisdom held that lasers would never work for lithography. Jain had to develop the complex optics to evenly illuminate the silicon wafer with the laser and to engineer a wafer coating of photosensitive material, or photoresist, that responded to ultraviolet light. In 1982 he succeeded—and within a decade, the big semiconductor manufacturing equipment companies offered commercial ultraviolet lithography tools, or steppers, capable of executing chip designs at the high resolution necessary.

It's hard to overstate the importance of myriad essential engineering advances like this one in semiconductor manufacturing. The innovations kept Moore's Law—the idea that the number of transistors on a chip doubles every two years—from hitting a wall. Now, commercially available microprocessors contain more than 7 billion transistors, packing more than 8.75 million on every square millimeter. Each individual feature is only 22 billionths of a meter wide—4,000 of them side by side span the width of a human hair. The consequences have been profound.

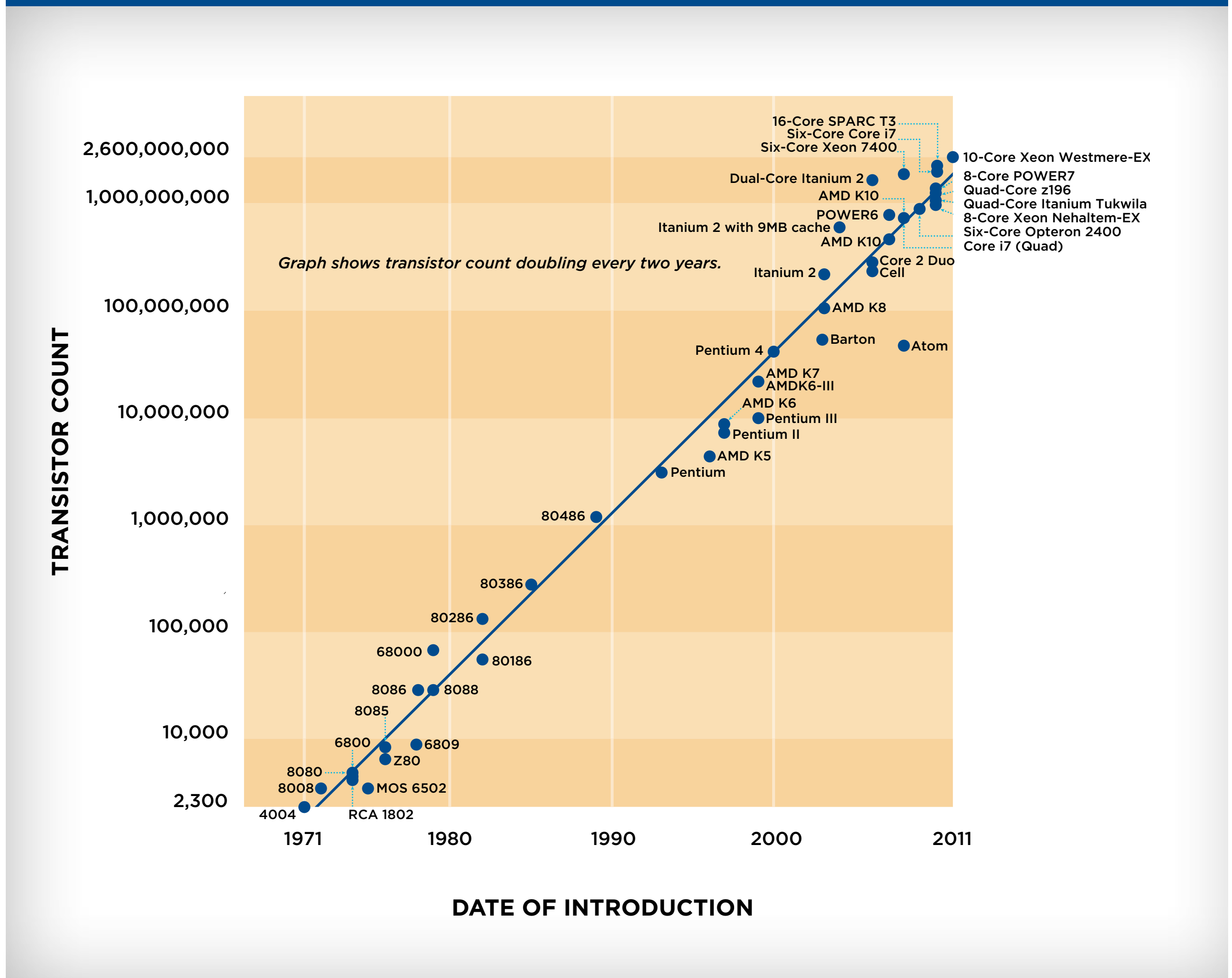
Without the vast increase in transistors on a chip and the resulting huge leap in computing power—combined with the complex software needed to unlock that power and the falling costs that have made products accessible—we'd have no super-realistic video games or our now-essential smartphones. Supercomputers wouldn't be modeling weather patterns and dangerous storms days in advance, accurately predicting blizzards in Colorado and floods in Bangladesh—and saving countless lives. Companies wouldn't be doing most of the design work for fuel-efficient airplanes through simulations alone.

Now, thanks to sophisticated silicon chips, autonomous submersibles can chart ocean currents to monitor the health of the oceans and answer questions about climate change. Flying drones track orangutans in Indonesia and ivory poachers in Africa.

Computers on the electrical grid balance supply and demand, ensuring that the lights stay on in our homes and factories keep humming. Meanwhile "smart" meters enable the solar panels springing up on hundreds of thousands of roofs to feed clean power back into the grid.

Or consider another science and engineering breakthrough. Physicists had known since 1856 that the resistance to electrical current flowing through many metals changes slightly in a magnetic field, a phenomenon called magnetoresistance. In 1988, French physicist Albert Fert thought he could amplify the effect by designing materials made up of very thin layers of metals. He tried sandwiching chromium with iron—and achieved a magnetoresistance 10 times that of standard metals. About the same time, German physicist Peter Grünberg independently managed a similar feat.

MICROPROCESSOR TRANSISTOR COUNTS FROM 1971-2011 AND MOORE'S LAW



Computer disk drives already depended on magnetoresistance to read data stored magnetically on spinning discs. But Fert's and Grünberg's "giant" magnetoresistance promised dramatic gains in storage density—if a series of complex engineering and materials science problems could be solved. They could. By 1994, IBM engineers had produced prototype hard disks that stored 17 times more information per square inch than previous devices.

Fert and Grünberg shared the 2007 Nobel Prize in physics. By then, their discoveries and subsequent advances had enabled the capacity of data storage devices to double every year—even faster than Moore's Law. Now, what once seemed like science fiction is part of daily life: Movies on demand. Entire libraries of books or music in the palm of your hand. Maps and photographs of virtually every street in the United States—and many countries around world—accessible at a keystroke. With big data centers and complex software, companies now manage and control vast supply and distribution chains, track customers' purchases and preferences, and offer unprecedented levels of personalized services.

Yet smaller transistors and expanding data storage are just a tiny fraction of the engineering wizardry that has transformed our lives. Light-emitting diodes and liquid crystal displays have made flat-panel video screens ubiquitous, from living rooms and stadiums to myriad handheld devices and heads-up displays. Glass fibers now carry terabytes of information around the world in flashes of light. GPS guides airplanes, farm tractors, ships at sea, and ordinary travelers in their cars or through their cell phones. Software and algorithms make sense of huge databases and connect people through social media. Cellular phone networks offer instant connections, even from distant mountaintops. And lithium-ion batteries provide hours of energy to run our cell phones, laptops, tablets, cameras, cordless power tools, and many other compact, lightweight mobile devices. The creators of fiber optics, lithium-ion batteries, GPS, cell phone networks, charge-coupled devices (the sensors in digital cameras), and liquid crystal displays—innovations that are now integral to life in the 21st century—have all been recognized by the nation's top engineering award, the National Academy

With computer chip "brains" an autonomous underwater vehicle can record the effect of ocean currents on fish larvae in the waters off Belize *(above left)*. Equipped with GPS technology, drivers can find their way in unfamiliar cities *(above)*.

Peter Grünberg *(left)* and Albert Fert independently developed "giant" magnetoresistance.

of Engineering's Charles Stark Draper Prize for Engineering.

Together, these advances have created a connected world rich in information that is expanding at a breathtaking clip. In 2014, we use smartphones to book flights, pay bills, hold meetings, and settle arguments at the dinner table. In Nigeria, farmers who never heard a phone ring as children now use cell phones to line up customers and get vouchers for seed and fertilizer. Governments connect directly with citizens, giving the public access to valuable data on contracts and spending, and taking action on complaints. With a computer and an Internet connection, a soldier fighting a distant war can sing his three-year-old daughter to sleep as she watches on the home computer screen. High-speed connections have become as important for economic growth and commerce as railroads and highways once were, as cities like Chattanooga, Tennessee, attract new companies with broadband networks. People living in Beijing, Berlin, and Boston can work together almost as if they were in the same room.

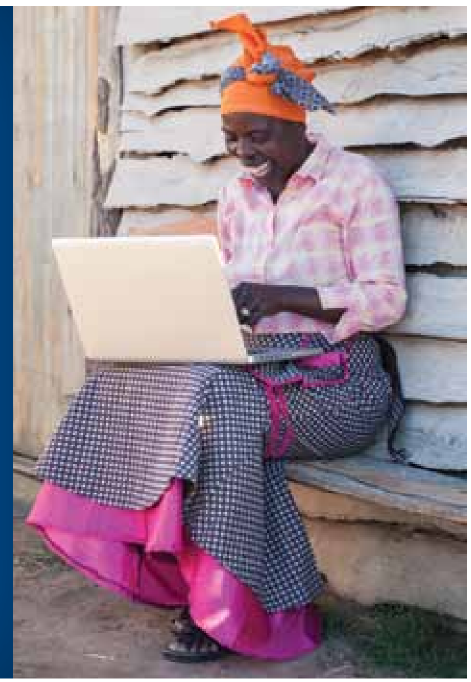
Meanwhile, social media are creating communities and connecting friends, while also becoming a potent political tool. In the week before Egyptian president Hosni Mubarak resigned in 2011, for instance, the number of tweets about political change in Egypt climbed to 230,000 a day. Protest and political videos went viral, with millions of views. In the Arab Spring, concluded a University of Washington study, "social media carried a cascade of messages about freedom and democracy across North Africa and the Middle East, and helped raise expectations for the success of political uprising."

Of course, this connectivity isn't necessarily all sunshine and roses. For instance, many would say that the Arab Spring has failed to deliver on its initial promise of spreading freedom and democracy. The new world also comes with thorny new problems. Operating around the clock, global engineering enterprises, including manufacturers of everything from clothing, cell phones, and computers to appliances, automobiles, and aircraft, can assemble talent globally—and also outsource IT tasks and other jobs from high-wage countries like the United States to lower-wage developing countries.

By breaking through the security walls of company databases, thieves have been able to steal credit card information and other valuable data. Terrorists, like every other kind of organization, have become adept at using the Internet to communicate and plan. Many people are overwhelmed by the flood of seemingly urgent e-mails and by information in general. Meanwhile, fierce debates are raging about governments spying on the communications of their own citizens, about companies collecting vast amounts of information on people's online habits and behavior, even about whether to use cameras to monitor traffic and fine drivers remotely for running red lights or speeding.

The good news, though, is that many of these problems will likely be solved by more innovation. Where necessary, government policy and regulation can address many issues as well, in a feedback loop that relies on continued engineering creativity.

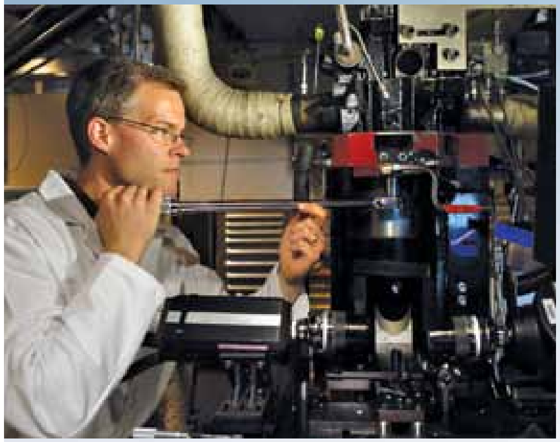
Whether chatting with a family member on the other side of the world or holding business meetings with far-flung colleagues, people communicate via computers wherever they can connect to the Internet.



Bald eagles came back from the brink of extinction thanks to the elimination of chemicals like DDT from the environment.

A Cleaner World

A whole generation in the United States has grown up without memories of rivers catching on fire, smoke darkening Pittsburgh, smog hanging over Los Angeles, or of acid rain rendering one-quarter of the lakes in the Adirondacks too acidic for fish to live. They don't remember that on cold winter mornings across much of America, the air was heavy with the stomach-churning odor of unburned hydrocarbons as people cranked their car engines.



Although we still face daunting environmental challenges—oil and chemical spills, nutrient pollution in rivers and lakes, ocean acidification, habitat loss, and species extinction—consider how much progress has been made. On sunny days, cities now sparkle under blue skies most of the time. For the most part, rivers and lakes are clean enough for swimming. The ozone hole is closing, and the burden of lead in our bodies is dropping. Eagles and many other species have rebounded from the chemicals that almost caused their extinction. Americans even use less energy per person—about 10 percent less—than they did in 2007. Many of these improvements—spurred by governmental policy and public demand—required new technologies created through engineering innovation.

Researchers at Sandia National Laboratories and other labs, for example, worked with auto and truck companies to create ways to burn motor vehicle fuel more cleanly and efficiently. That step forward has been especially important for diesel engines, whose exhaust is harder to clean with catalytic converters than that of gasoline engines. Add in a host of other innovations from the auto industry, such as variable valve timing, direct ignition, and up to a hundred microcomputers in a single car, and today we have vehicles that are more than 95 percent cleaner than those in the 1960s. The plumes of black smoke once billowing from trucks plying the nation's highways have mostly vanished. Cars and SUVs are much safer and more powerful than in

Below left: Mark Musculus and colleagues at Sandia National Laboratories use optical diagnostic techniques to identify pollutants in motor vehicle fuel.

decades past, and packed with features like power windows; antilock brakes; air bags; and a number of safety, comfort, and handling control and convenience features. Yet average fuel economy has climbed to 24.8 miles per gallon in 2013 for cars and light trucks, up from 20.8 mpg in 2008 and far above the 1975 level of 12.9 mpg. Many models achieve more than 40 mpg.

The result? Look at Los Angeles as just one example, where the number of health advisories from unhealthy ozone-laden air dropped from 144 in 1988 to 0 in 2012.

Moreover, the pace of innovation in automobiles and other vehicles continues to accelerate. Buyers can now choose from more than two dozen hybrid models, the most efficient of which are rated at 50 mpg combined city and highway driving running on gasoline. Consumers can also select from more than a dozen all-electric models, with companies and states racing to build charging stations on major highway routes so that owners won't suffer from "range anxiety"—the fear of running out of juice. On January 30, 2014, two electric cars headed out across the entire United States from Los Angeles to New York City, enduring blizzards, freezing temperatures, a blinding sandstorm, and driving rain. They made the journey in about 76 hours—including about 15 hours of charging time.

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Energy efficiency has been and remains the low-hanging fruit for reducing reliance on fossil fuels, and engineers have done much in recent decades to conserve fuel and reduce pollution by designing energy-efficient buildings. "Green" roofs both help reduce the urban heat-island effect and cut pollution from storm-water runoff that contaminates rivers and streams. Many energy-saving technologies, including coated glass windows that conserve interior heat in cold weather and deflect exterior heat in warm weather, were engineered at the Lawrence Berkeley Laboratory in California under the direction of Arthur Rosenfeld, a particle physicist by training who went on to become a member of the California Energy Commission. The efforts of the commission, which included pioneering efficiency regulations, have helped reduce the amount of energy used per person in California to a level about 40 percent below the nationwide average.

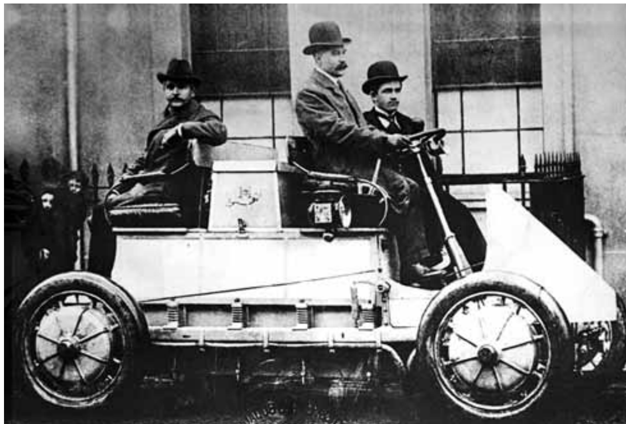
Similar progress has been made on many other fronts. Refrigerators, TVs, and computers are far more energy-efficient than they were a quarter century ago because of engineering advances and new efficiency standards. Tollbooths are being replaced by automated toll collection systems that speed travel as well as reduce pollution.

Companies have harnessed a technology called cavity ring-down spectroscopy to engineer mobile methane detectors that can spot leaks of natural gas, which consists primarily of methane, a greenhouse gas.

Farmers use yield sensors, autopilot-guided tractors, variable computer-controlled sprayers, and other recent advances to apply just the needed amount of fertilizer and water to each small patch of their field. The technology saves money and water, boosts yields, and reduces the nutrient runoff that flows into rivers and lakes, another environmental concern. Along with polluted runoff from parking lots and pavements, nutrient runoff has triggered blooms of toxic algae and created vast "dead zones" that kill marine life over thousands of square miles in the Gulf of Mexico.

Keeping the air and water clean, protecting people from chemicals and toxins, and reducing greenhouse gas emissions are never-ending struggles. Engineers aren't the only troops in these continuing battles. But the solutions they create have been—and will continue to be—the essential part of any victories that we achieve. ●

Two all-electric Tesla Model S vehicles drove from Los Angeles to New York City in the middle of winter. During one overnight leg the team endured more than 12 inches of snow, icy roads, and high winds. The only breakdown occurred with one of the gasoline-powered support vehicles.



HYBRIDS

An Idea Whose Time Arrived at Last

Strictly speaking, hybrids—vehicles that can use more than one form of energy—aren't new. Most long-haul railroad locomotives are hybrids, with a diesel generator that provides power to massive electric motors. And the first hybrid automobile actually dates back to 1900, when Ferdinand Porsche, working for carriage builder Jacob Lohner & Co. in Vienna, Austria, used two gasoline generators to drive electric motors built into the vehicle's wheel hubs *(above)*. Despite constant refinements to the design, very few Lohner-Porsche hybrids were made or sold. The idea was simply too far ahead of its time.

Now fast-forward 100 years to August 2000, when the 2001 Toyota Prius hybrid began arriving in dealer showrooms in the United States. With EPA mileage ratings of 52 mpg, the Prius was named Best Engineered Car of 2001 by the Society of Automotive Engineers. In 2002, Prius sales topped 100,000 worldwide. The first plug-in hybrid, the Chevrolet Volt, and first all-electric vehicle, the Nissan Leaf, arrived in December 2010.

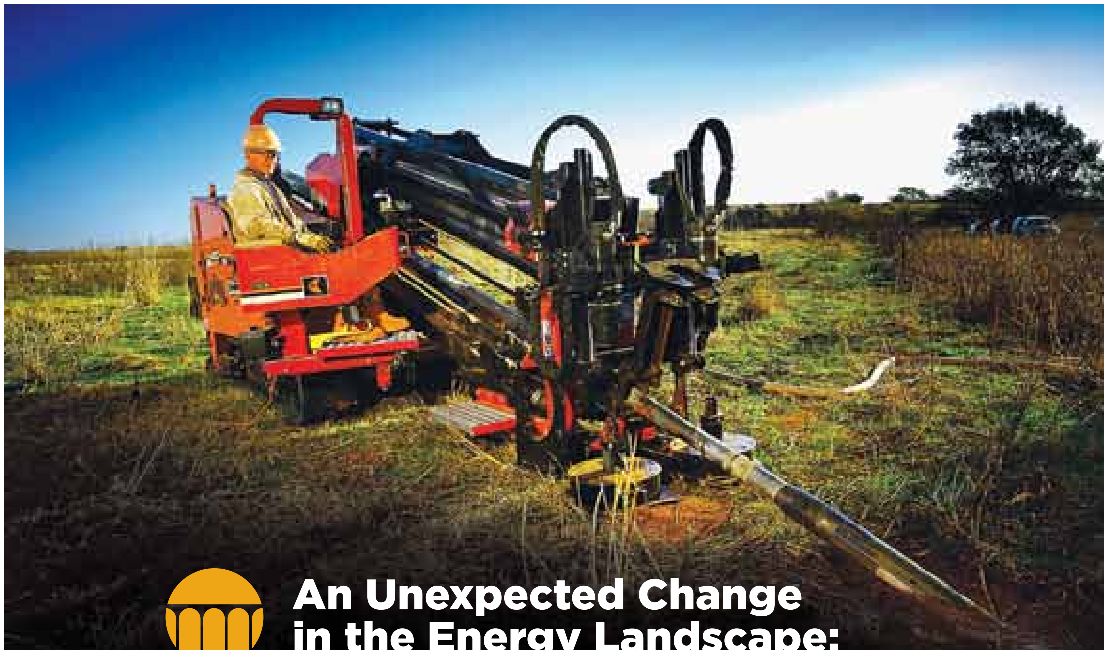
Hybrids come in two main types. In a "series" hybrid (like the Lohner-Porsche) there is only one path to power the wheels—namely, an electric motor that gets its electricity from either high-capacity batteries or an onboard generator typically fueled by gasoline. The generator only runs when the batteries are low on power. The gas engine/generator recharges the batteries, which are also recharged through regenerative braking—capturing energy normally lost during braking and using the electric motor as a generator to store it in the battery.

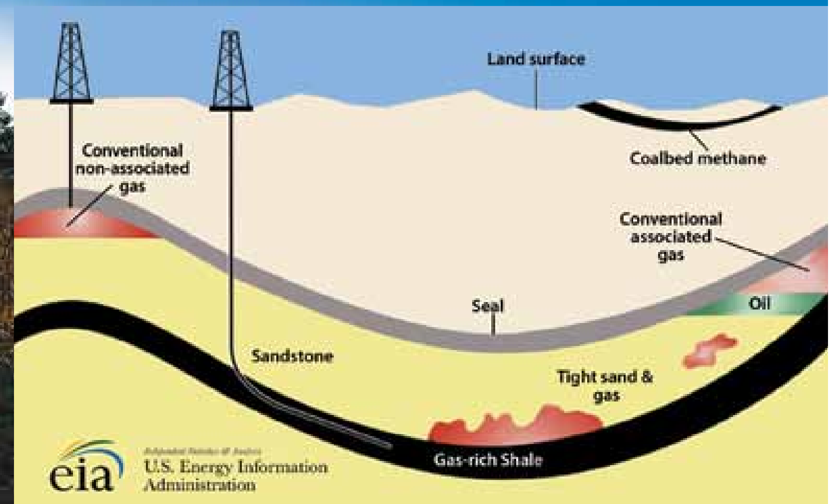
A "parallel" hybrid has two complete power trains—usually a gas-fueled internal combustion engine and a battery-powered electric motor—that can work individually or together to turn the wheels and move the car. A parallel hybrid switches between the systems to get the greatest efficiency. As with a series hybrid, the battery is charged by the gas engine/generator and by regenerative braking,

Plug-in hybrids, which may be either serial or parallel, have the added ability to charge their batteries by an outside power source. They also have larger battery packs than regular hybrids, making it possible to drive using only electric power.

In 2012, with gasoline prices averaging $3.60 per gallon (and pushing $4 in some places), Americans bought more than 50,000 plug-in electric vehicles. In the first half of 2013, as battery costs were dropping—and with so many more hybrids and all-electric cars to choose from—Americans bought double the number of plug-in electric vehicles they purchased in the same period in 2012.

Ferdinand Porsche would no doubt be pleased to see his idea finally catching on.





An Unexpected Change in the Energy Landscape: The Shale Gas Boom

In the 1970s, some warned that the world was on an unsustainable path and that before too long we'd run out of oil and food. Lights would dim, factories would slow, people would starve, civilization would crumble. The oil crisis of the mid-1970s, with long lines of cars waiting for gasoline, seemed to be a harbinger of that grim future. But advances in hybrid crops have sustained food supplies and, for the United States at least, new supplies of oil and gas appeared seemingly out of nowhere due to engineering innovation.

As shown in the schematic at *far right above*, horizontal drilling provides greater access to natural gas trapped deep in a shale formation. First, a vertical well is drilled to the desired depth. Then the drill bit is turned to bore a well horizontally through the reservoir.

In 1997, Mitchell Energy was in trouble. Production from the company's gas wells in Texas was falling. Reserves were declining. So founder George Mitchell took a gamble. Bucking the conventional wisdom—and the advice of top executives in his own company—Mitchell decided to step up drilling in the Barnett Shale.

Geologists had long known that shale formations deep underground contain large amounts of gas and oil. But freeing the gas trapped in the rock is difficult. Pumping down thick, viscous liquid under high pressure can fracture the rock (a process called hydraulic fracturing, commonly known as "fracking") and liberate the fuel. Although hydraulic fracturing itself dates back to the 1940s, it wasn't working in the shale formations, where production at most wells that used the technique quickly petered out.

The job of successfully extracting gas from shale fell to Mitchell engineer Nicholas Steinsberger. He experimented with different liquids and gels, with little success. Then a contractor accidently pumped down fluid that was more watery than usual—and more gas than expected came up. Could mostly water be the answer? Steinsberger decided to find out.

"Most everyone thought Steinsberger was out of his mind," wrote Gregory Zuckerman in his 2013 book, *The Frackers: The Outrageous Inside Story of the New Billionaire Wildcatters.* He wasn't. With his watery fracturing fluid, his wells kept producing and producing and producing.

Steinsberger's innovation was a key piece of the puzzle of how to tap into the nation's huge deposits of shale gas and oil, but it built on numerous other engineering advances. The most important was figuring out how to drill deep and then turn the bit sideways to drill horizontally for up to several miles. That approach is crucial for shale hydrocarbons, which lie in "thin" horizontal formations and, without horizontal drilling, would not be economical to produce.

An important prior development came from engineers and scientists at national labs (Sandia and others), who developed technologies in partnership with the Gas Research Institute (now the Gas Technology Institute) to peer deep underground. Using microseismic tools and sensors, the engineers were able to

LOWER 48 STATES SHALE PLAYS

Shale gas is found in shale "plays"—shale formations containing significant accumulations of natural gas. As of 2009, 87 percent of the natural gas consumed in the United States was produced domestically.

Thus, some see the natural gas boom gas as a cleaner "bridge" to a future with more renewable energy because it produces half the carbon dioxide that burning coal does to generate the same amount of electricity.

"see" the shale deposits and watch how those deposits change with extraction. They could then guide drills directly into underground gas pockets or concentrations of oil. The new technologies dramatically reduced the number of "dry" holes.

Once successfully demonstrated by Mitchell Energy, the combination of underground vision tools, horizontal drilling, and hydraulic fracturing touched off a drilling boom in gas and oil shale formations in other regions of the country, such as the North Dakota's Bakken Shale and the Marcellus Shale under West Virginia, Ohio, and Pennsylvania. The result has been a flood of domestic natural shale gas and shale oil that turned the United States into the world's largest producer of petroleum and gas products in 2014—an astonishing development. With gas supplies abundant and prices low, companies like Dow Chemical have invested billions of dollars in new chemical-manufacturing facilities in the United States, creating jobs and boosting the economy. Utilities are switching from coal to cheaper, cleaner gas, reducing pollution and greenhouse gas emissions. U.S. coal use has dropped 18 percent since 2007. Meanwhile greenhouse gas emissions in the United States have fallen by about 10 percent since 2005—in part because of the substitution of natural gas for coal, but also because of the Great Recession, the growth of renewables, and improved efficiency.

Although an energy boon, the rapid growth of hydraulic fracturing has generated controversies about its safety and environmental and health effects. Drilling for shale gas has sometimes been associated with triggering small earthquakes as well as with contaminated drinking water, polluted streams, and illness. The thousands of gallons of water needed in each well to break open the shale has led to concerns about streams and wells going dry—though engineering improvements make it possible to recycle the fracturing water, and efforts are under way to eliminate the use of water all together. Keeping in mind that since the late 1940s about a million wells have been drilled with a total length of 150,000 miles, the problems are relatively few and appear manageable with innovation and regulation.

Another concern is what the boom in natural gas may mean for the climate. Long term, according to the 2014 National Climate Assessment, if carbon dioxide keeps accumulating in the atmosphere at the current rate, the world could warm by as much as a dangerous 10 degrees Fahrenheit by the end of the century. With moderation of the accumulation rate by significant emission reductions globally, the assessment estimates, the increase could be as little as 3 degrees Fahrenheit. Thus, some see the natural gas boom as a cleaner "bridge" to a future with more renewable energy because it produces half the carbon dioxide that burning coal does to generate the same amount of electricity. Others worry that, without sufficient control of the extraction process, natural gas leaking from wells and pipelines could put more greenhouse gases into the atmosphere than burning coal. As a practical matter, however, even in the most optimistic scenario, renewable resources will not meet America's energy needs for 30 to 50 years. For that reason, many experts argue that the switch from coal to natural gas is a welcome development.

The good news from the standpoint of the environment is that some of the technology needed to curb greenhouse gas emissions from the use of fossil fuels already exists. Power plant industry engineers have developed and successfully demonstrated processes using chemicals like amines or chilled ammonia that capture the carbon dioxide from smokestacks.

What to do with all that captured carbon remains a challenge. Scientists and engineers are investigating a number of ideas. One key is to pump the carbon deep underground to sequester it from the atmosphere. Another possibility is to use carbon in products like concrete by combining exhaust carbon dioxide, water, and calcium.

Renewable Energy

Even as engineers work to find ways to deal with carbon in the oil, gas, and coal industries, engineering innovations are boosting alternative energy sources. A good example is wind-power technology. Using taller, stronger towers; huge carbon fiber blades more than 250 feet long; better aerodynamics; and improved software and controllers, engineers at companies like Vestas, Siemens, General Electric, and Gamesa have created electric generators powered by wind that are more powerful, more efficient, and more cost-competitive than those in use just a few years ago. In 2012, the United States added more new electric power generation capacity from wind than from any other source, even though the price of natural gas was low. (Of course, turbines produce on average less power than their rated capacity because the wind doesn't always blow.) Now, in 2014, countries and companies can envision a major additional expansion of wind power, as engineers figure out how to safely erect giant wind turbines in coastal waters to tap into powerful offshore breezes, and how to solve the challenges of storing and distributing the energy so that electrical power will be available when wind speeds drop.

The progress in solar energy has been equally dramatic. In 2014 a solar panel costs one-tenth of the price in 1990—and one-hundredth of the price in 1977—due to a whole series of improvements. Engineers have created more efficient processes for making the polycrystalline silicon thin films and other materials used for solar photovoltaic panels. They've improved the efficiency of solar cells so the cells capture more of the sun's energy as electricity, and they've increased the usable yield from the lithographic tools that make the cells. They have also

At the Reese Technology Center in Lubbock, Texas, the DOE/Sandia Scaled Wind Farm Technology (SWiFT) facility's advanced testing and monitoring will help researchers evaluate how larger wind farms can become more productive.

As the cost of solar panels has come down, residential installation has risen. In 2013 in the U.S. solar power was second only to natural gas in new electricity generation.

New York City's iconic Empire State Building has undergone an energy-efficiency upgrade that saved $2.4 million in its first year. The upgrade included refurbishing all 6,514 windows, new building management systems controls, a Web-based tenant energy management system, and elevators that can send excess energy back to the building's grid.

figured out how to install panels more cheaply.

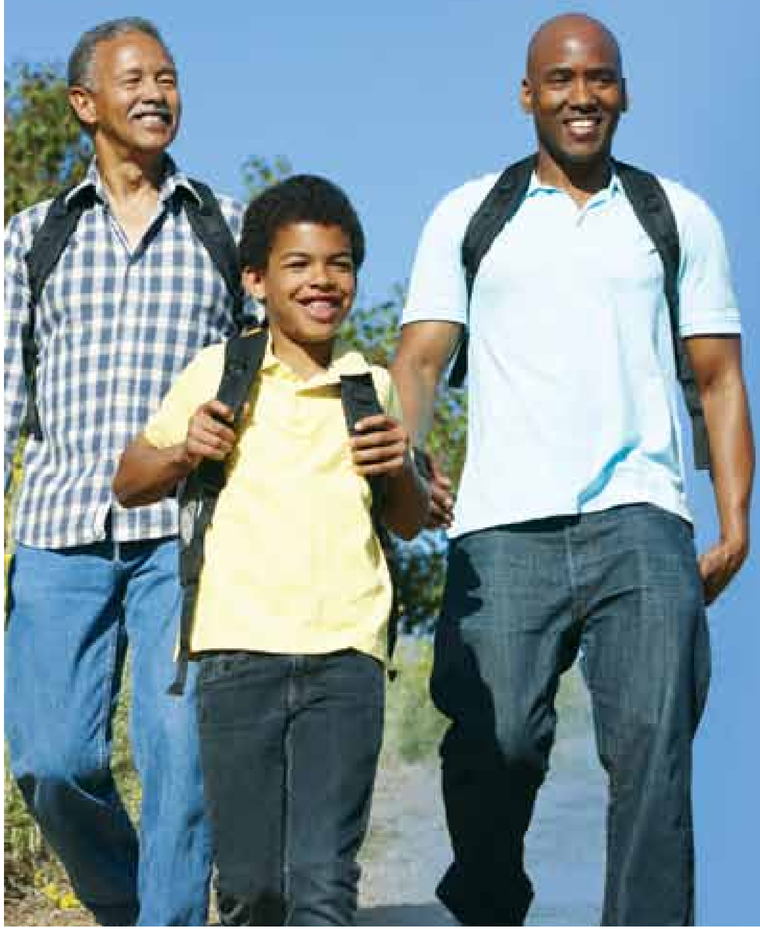
The result has been a rapid acceleration in adoption of solar energy. In 2013, solar outpaced wind in new electricity generation capacity in the United States, coming second behind natural gas. The state of California alone added more rooftop solar systems in 2013 than over the previous 30 years, bringing the state's total solar capacity to 4,000 megawatts—as much as two or three big nuclear plants. Of course, in 2014 solar and wind are still small contributors to the nation's electricity supply, at about 7 percent of overall generating capacity (bringing the total of power from renewable sources, with hydro, to about 15.5 percent of all national electric power requirements).

The alternatives to fossil fuels also go beyond renewable energy. For example, although cheap natural gas has killed plans for some new nuclear power plants and accelerated the retirement of existing ones, two new nuclear units are under construction in Georgia and new technologies for smaller, modular nuclear plants are being considered. Meanwhile, despite daunting economic challenges, technical progress has been made in unlocking the energy stored in plant cellulose, and one factory in Mississippi makes biofuels from feedstock like yellow pine. Perhaps most encouraging and promising, the world continues to make huge strides in energy efficiency, especially in buildings. In fact, U.S. consumption of both electricity and gasoline has declined since 2007, in part because of the recession but also because of improved efficiency.

The key point: the world now has the technological capability to rely on more diverse sources of energy. In some regions, such as Hawaii, where electricity is costly, renewable power already has become economically and operationally competitive. In others, as California's experience demonstrates, policy decisions and incentives can tip the balance toward cleaner, more sustainable sources, while also stimulating further technological innovations.

Looking back to the dark days of past energy crises, who would have predicted then that in 2014 oil and gas would be plentiful in the United States? That massive wind farms would sprout up everywhere from the Texas plains to the seas off the coast of Sweden? And that in 2013 Denmark would produce one-third of its electricity from wind alone—with a goal of 50 percent by 2020? True, we still worry about a sustainable future as the consequences of our warming planet become clearer. But the technological advancements of the last quarter century allow us to be hopeful, if still cautious, about our options.

Humans now live longer and healthier lives than at any other time in history. Average life expectancy for a child born this year in the United States has climbed to 79 years, up from 75 years in 1990 and 70 years in 1964.



A Healthier World

Zapping the heart with little pulses of electricity from implantable pacemakers has prevented millions of deaths, boosted lifespans, and improved quality of life since the late 1950s. And by 2008, the devices had shrunk to less than two inches across.

But that wasn't small enough, thought engineers at medical device maker Medtronic. They set out to build a pacemaker one-tenth that size—a device so small it could be implanted inside the heart by threading it up through a blood vessel. That would eliminate the need to make an incision in the chest to insert the electrical leads for the traditional pacemaker, which sits in a pocket under the skin. Moreover, by fitting inside the heart, the new miniature device, known as Micra, would eliminate the most problematic part of the system—the electrical wire from the device to heart itself.

Was it even possible? The engineers were forced to rethink the whole approach, designing all the electronics—even the battery—as one unit instead of as an assembly of individual components, as in previous devices. They also needed to slash the power consumption dramatically so that a tiny battery could last for 7 to 10 years. They succeeded. In late 2013, the world's smallest pacemaker was implanted in its first human patient. It is now undergoing clinical trials to verify safety and effectiveness.

The tiny leadless pacemaker is just one of the countless medical advances created by engineers over the last quarter century. Doctors

In the course of the last half century, biomedical engineers have reduced the size of pacemakers from external boxes about the size of a car battery to implantable devices barely larger than a 9-volt battery *(left)*. A proposed new model—as tiny as a vitamin capsule *(above)*—could be threaded into the heart through a blood vessel.

After a few sessions of training with a Modular Prosthetic Limb (MPL) developed at Johns Hopkins Applied Physics Lab, Tech Sgt. Joe Delaurier could control the MPL via signals generated by muscles beneath the skin of his residual limb.

can now replace faulty heart valves with a catheter threaded through an artery instead of open-heart surgery. They can prop open narrowed arteries with stents that dissolve, if desired, after doing their job. Improvements in DNA sequencing have helped researchers spot genes linked to Alzheimer's disease and other scourges. The resulting explosion of genetic knowledge, in turn, has led to targeted cancer drugs with fewer side effects and to new ideas for treating other diseases.

Meanwhile, breakthroughs abound in other arenas. The first vaccine that prevents cancer (a vaccine against human papillomavirus, which causes cervical cancer) was introduced in 2006. Prosthetic limbs have enabled amputees to run and dance—and advanced to the point where they can be controlled by electrical impulses from the brain.

In June 2014, researchers at Boston University and Harvard University reported successful results, with an artificial pancreas, which uses sensors, a smartphone, and an insulin-delivery system to precisely control the blood sugar levels in a small sample of people with type 1 diabetes. And neurological diseases like Parkinson's and epilepsy are being treated with electrical stimulation of the brain.

Humans now live longer and healthier lives than at any other time in history. Average life expectancy for a child born this year in the United States has climbed to 79 years, up from 75 years in 1990 and 70 years in 1964. Even greater gains have been made all over the world. Just one technology—vaccination—has eradicated smallpox, virtually eliminated polio, and dramatically reduced measles, mumps, and diphtheria. Child mortality rates continue to drop.

Forging a healthier world is not just a matter of preventive technology like vaccines, however. Great improvements have come from changes in social attitudes and habits as well. For example, decreases in smoking brought tobacco-related deaths in the United States down by about 35 percent between 1987 and 2002. Higher seat belt use and crackdowns on drunk driving, in addition to numerous safety improvements in vehicle design, have cut traffic deaths to just over 10 per 100,000 Americans, down from 16 in 1995 and 23 in 1950.

Some of the current trends are going in the wrong direction. Today, according to United Nations estimates, people with preventable waterborne diseases occupy half of the hospital beds worldwide. In the United States, the increasing incidence of obesity and of diseases triggered or exacerbated by lifestyle, such as diabetes, is threatening to roll back gains in lifespans.

Medical technologies and procedures also can raise the cost of health care without actually improving medical outcomes. And millions of Americans—and billions of people

PRECIOUS COMMODITIES

Safe drinking water is scarce in many parts of the world, where people often have to walk great distances to a source of clean water and then carry heavy containers back to their homes *(above)*. Solving that problem would be an enormous contribution to human health. Meanwhile, bioengineers have created gene-spliced crops, such as soybeans *(below)*, with increased yields to help feed the world's hungry.

around the world—lack even basic health care.

Clearly, good health is about far more than sophisticated MRI machines or other cutting-edge technologies. But engineering has key roles to play in public health challenges. Basic engineering technology can bring proper sanitation and clean water to millions of people who now lack safe water, making perhaps the single greatest possible contribution to human health. Development of electronic health records, interconnected information systems, and data mining techniques can help doctors compare health outcomes after different treatments. The tools of system engineering then make it possible to design and monitor more effective health care delivery processes. Meanwhile, our increasingly interconnected world allows telemedicine and robotic surgery to deliver quality medical care in currently underserved regions, whether in the United States, Africa, or war zones in Afghanistan. And new devices—purchased over the Internet for about $100—can monitor physical activity and diet and might help people lead healthier lives.

As the last half century has demonstrated again and again, people naturally embrace the innovations that improve their lives and offer new capabilities. Engineering has enabled us to leap from tinny-sounding transistor radios and rotary dial phones to smartphones, from bulky black-and-white TVs to giant flat displays and virtual reality. We have altered genes to boost crop yield; developed new materials that make tennis rackets more powerful and airplanes faster, safer, and more fuel efficient; reduced pollution; and developed new sources of energy. Entire industries have been transformed, from publishing and manufacturing to retail and politics.

New engineering creations have enriched our lives, expanded our potential and our reach, even deepened our understanding of what it means to be human and of where we fit into the universe. Nor is this the end of the story. As a peek into universities, national laboratories, and companies around the country would quickly show, the pace of innovation isn't slowing.

The path to the future will never be easy or smooth, of course. The sobering truth is that even as engineering invents ways to solve myriad human and societal problems, the solutions themselves may have unintended, adverse consequences. So it is through a combination of individual choices and public policies that we constantly strive to maintain the right balance of benefit and cost. The heartening truth is that as costs become burdensome, the challenge to restore balance will be met by the most inexhaustible resource that we have—human ingenuity, which gives us discoveries derived from science and innovations created by engineering.