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Soon our radios will be competing with one another for the airwaves. Game theory shows how to make them cooperate. *By K.J. Ray Liu*

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After lighting our world for more than 130 years, the incandescent lightbulb is on its way out, making way for more energy-efficient alternatives. In a fond farewell, we look back on its evolution and our years of basking in its warm yellow glow. *By Brian Bowers*

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THIS PAGE, TOP: FERRARI; BOTTOM: SERGE BLOCH

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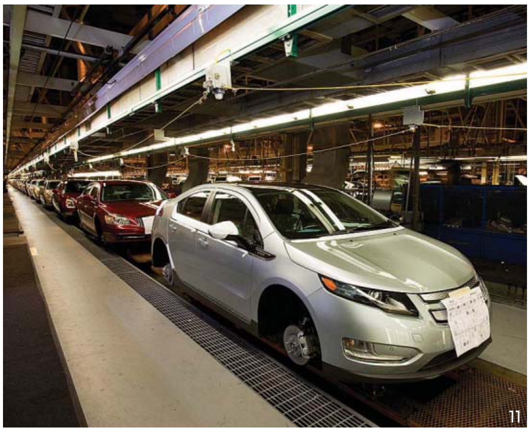
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CLOCKWISE FROM LEFT: GENERAL MOTORS CO.; ISTOCKPHOTO; RAY LARSEN

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AVAILABLE 1 APRIL

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Big news stories often have a neglected tech angle. Whether it's French audio engineers silencing those droning vuvuzelas during broadcasts of last year's World Cup, Internet shutdowns in Egypt and Libya, the debut of Motorola's Xoom tablet, or IBM Watson's decisive victory at "Jeopardy," "This Week in Technology" host Steven Cherry and his expert guests cover all the angles.

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AVAILABLE 7 APRIL

IEEE HELPS BRING ELECTRICITY TO HAITI
A group of members have spent the last two years designing and building six trailers that house solar generators for the people of Haiti. Read about their work.

SHOE RADAR
Signals from pocket-size GPS navigation systems can't penetrate many places soldiers and emergency workers must reach. A paper published in a recent *IEEE Transactions on Microwave Theory and Techniques* describes an inertial navigation system small enough to be mounted on or in a shoe for such situations.

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back story

A Car for the Man Who's Driven Everything

WHAT WOULD a man who's driven just about every exotic car model on the planet have in his own garage, if money were no object? We posed the question to Lawrence Ulrich, our reviewer of this year's top 10 tech cars (in this issue), and his answer was quick and firm.

Was it the Mercedes-Benz SLR McLaren, a half-million-dollar gull-wing stunner? Or the Audi R8 5.2, with a V-10 engine and more carbon fiber than an America's Cup yacht? Or perhaps the Bugatti Veyron 16.4, the fastest production car in the world? "The Bugatti's a car for Saudi oil sheiks, at US $1.4 million," Ulrich scoffs.

Auto writers themselves tend to like BMWs, the odd Porsche, and the up-and-coming Audi, Ulrich says, because of their "mix of high performance and reasonable practicality." Yet this year, unlike last, nothing from BMW made our list. The Bavarian motor lords just didn't show off enough new technology. That's what makes *IEEE Spectrum*'s list special—we look not just at the car but at the innovations it embodies.

So here's Ulrich's dream car: a Ferrari 458 Italia. One reason is that nobody's working harder on innovation than Ferrari. "I think it's fascinating," he says, "seeing them trying to balance their customers' demands for high performance with lower carbon-dioxide emissions and better fuel economy."

Another reason is how it feels driving that red, red Ferrari.

"Oh, there's a temptation to let 'er rip," Ulrich admits. He allows that once or twice he may have taken a few liberties with the speed limit around West Point, north of New York City. For the full-throttled test, though, he visited a racetrack in the Catskills.

Everywhere he went, he attracted swarms of onlookers. "On the road, people weave around in your blind spot, trying to shoot video with a cellphone," he says. "I get a kick out of it—there's such a sense of occasion driving a car like that, even for a guy like me who does this for a living."

The Italia looks fast even when it's idling. Pedestrians can then ogle the engine through a polycarbonate window, thoughtfully provided, Ulrich notes, "so you can see some of the money you've spent on the car." ❑

CITING ARTICLES IN IEEE SPECTRUM

IEEE Spectrum publishes two editions. In the international edition, the abbreviation INT appears at the foot of each page. The North American edition is identified with the letters NA. Both have the same editorial content, but because of differences in advertising, page numbers may differ. In citations, you should include the issue designation. For example, the first page of Update is in *IEEE Spectrum*, Vol. 48, no. 4 (INT), April 2011, p. 9, or in *IEEE Spectrum*, Vol. 48, no. 4 (NA), April 2011, p. 11.

CRAIG A. GRANT

contributors

SERGE BLOCH, whose illustrations accompany the photo essay “Lights Out” [p. 42], has drawn for *The New York Times*, *National Geographic*, and *GQ*. He won a gold medal from the Society of Illustrators in 2005 and the Bologna Ragazzi award in 2007. Based in Paris, he is also a children’s book author. His creations include the hero Samsam, inspired by his son Samuel’s love for a Batman costume.

BRIAN BOWERS is an electrical engineer who worked as an examiner in the British Patent Office, then became a curator in London’s Science Museum. There he focused on the electrical engineering and lighting collections. For Bowers, who wrote “Lights Out” [p. 42], lighting is something everyone can relate to at some level of complexity, from simple oil lamps and candles to the abstruse semiconductor physics of the LED.

K.J. RAY LIU, a professor in the department of electrical and computer engineering at the University of Maryland, began applying game theory about a decade ago to wireless communication—a subject he discusses in “Cognitive-Radio Games” [p. 38]. Although game theory is less than a century old, people have relied on these kinds of ideas since the Stone Age. “It’s in our blood,” he says. It’s only fitting, then, that soon it’ll also be in our phones.

PAUL McFEDRIES has written *IEEE Spectrum*’s Technically Speaking column since 2002. In “The Locavore’s Dilemma” [p. 25], he defines some neologisms for local food—grown no farther than 100 miles from home and perhaps as close as your own window box. He has written more than 70 books; the latest include *The Facebook Guide for People Over 50* and *Windows Home Server 2011 Unleashed*. His Web site, Word Spy, tracks emerging words and phrases. This “lexpionage,” as he calls it, isn’t limited to technology terms: One recent find is “Lycra lout,” used to describe a rude cyclist who may inspire “bikelash.”

WILLIAM SWEET, who reviews two recent books about geoengineering in this issue [see p. 24], was formerly *Spectrum*’s news editor. The author of books about climate change and nuclear proliferation, Sweet also blogs about energy, the environment, and arms control. You can find some of his recent work on our Energywise blog.

JOHN VOELCKER, a contributing editor, has been following advanced cars closely for nearly a decade. He writes, reviews, and oversees editorial content for GreenCarReports.com and AllCarsElectric.com. He wrote “One Million Plug-in Cars by 2015?” [p. 9], because this U.S. goal has become a political football. After digging into the assumptions behind the numbers, he found that many people have been missing the bigger picture. “It’s not really about the specific number,” Voelcker says. “It’s about having a goal.”

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CLOCKWISE FROM TOP LEFT: SERGE BLOCH; KAREN HAMMOND; RANDI SILBERMAN KLETT (2); UNIVERSITY OF MARYLAND; VILEM KRIZ

Jobless Innovation?

IN A CRISIS, Americans always ask technology to come to the rescue. Military threat? Send in the drones. Health-care scare? Declare war on cancer and race for an AIDS vaccine. Energy shortage? Harness the sun and wind.

So inevitably, when the United States suffers from the highest levels of unemployment since the 1930s, the call for more technological innovation is heard from all directions.

Yet doubts abound that the stubborn Great American Job Bust won't be cured by President Obama's insistence that Americans "out-innovate...the rest of the world."

The problem is a new pattern of "jobless innovation." Exciting emerging technologies simply don't require many workers. Internet stars, such as Google, Facebook, and Twitter, employ far fewer people than the older tech titans. Silicon Valley, which remains by far the most fertile innovation cluster in the world, has experienced sharp declines in employment. The U.S. Bureau of Labor Statistics found in 2010 that techno-scientific employment fell by a staggering 19 percent over the course of the decade and that average wages in Silicon Valley also fell, by nearly 14 percent.

The trend toward jobless innovation in Silicon Valley provoked Intel cofounder Andy Grove to complain last year that "the U.S. has become wildly inefficient at creating American tech jobs" and that there is "misplaced faith in the power of [tech] start-ups to create U.S. jobs."

The jobless-innovation phenomenon results, in part, from globalization. Breakthroughs made in the United States are increasingly scaled up in Asia, robbing the country of expected employment benefits, says Grove, and important innovations are arising offshore, too.

Scholars have labeled this development "offshoring of innovation." They point to a marked rise in R&D activities in China and India and other rapidly growing economies. Offshoring creates a significant drag on U.S. employment. A new book, *The Global Auction: The Broken Promises of Education, Jobs, and Incomes,* argues that there now exists an ample pool of "cheap brainpower" outside the United States, largely in low-wage countries, with predictable effects on the U.S. labor market.

With so much R&D now occurring in India, China, and other parts of Asia (and also in Brazil, Russia, and South Africa), new graduates of science, math, and engineering programs in the United States experience "career uncertainty," reports Ron Hira, a professor of public policy at the Rochester Institute of Technology, in New York. In response to poorer job prospects, Hira has found an "astounding" decline in undergraduate computer-science enrollments, for instance, suggesting to him that a supply-side approach to employment—producing more graduates in computer science—may produce only more *unemployed* computer scientists.

Applying more technology to cure the jobs crisis carries another paradox. Many emerging technologies destroy jobs, in a process that the Austrian economist Joseph Schumpeter famously labeled "creative destruction." That innovations destroy jobs as well as create them challenges a major assumption behind the United States' secular faith, calling scientists and engineers to the rescue of society. Faith in the bounty of technological innovation is central to American optimism, a bipartisan doctrine. "We are the nation that put cars in driveways and computers in offices; the nation of Edison and the Wright brothers; of Google and Facebook," Obama declared in January. "In America, innovation doesn't just change our lives. It's how we make a living."

But when innovations undermine livelihoods, fears of new technologies, and especially automation, are understandable. Such fears have periodically traumatized Americans. In the 1930s, during the Great Depression, politicians and even engineers openly worried that the fruits of their labors might render their fellow human beings irrelevant. And in the 1950s the advent of mainframe computers spawned a new anxiety—that "machinery of the mind" would replace people who did perfunctory mental tasks.

To be sure, automation scares passed, and technology-driven job growth in the 1980s and 1990s eroded the credibility of pessimists. But ever more powerful computer networks are once more igniting paranoia. Observing the humanlike reasoning abilities of IBM's Watson, *Fortune* magazine asked in February, "Will IBM's Watson computer put your job in jeopardy?"

The unsettling scenario that jobless innovation will coincide with a wave of job-destroying innovation stands as a stark rejoinder to techno-optimists who openly espouse a belief in technology to deliver full (or greater) employment. The alternative to promoting innovation no matter what is tricky. How can Americans capture more of the employment associated with job-expanding innovations? They can start by examining their faith in the traditional equation of technological innovation with healthy job markets. —G. PASCAL ZACHARY

G. Pascal Zachary is a professor of practice at the Consortium for Science, Policy & Outcomes at Arizona State University.

A longer version of this article is available at http://spectrum.ieee.org/jobless0311.

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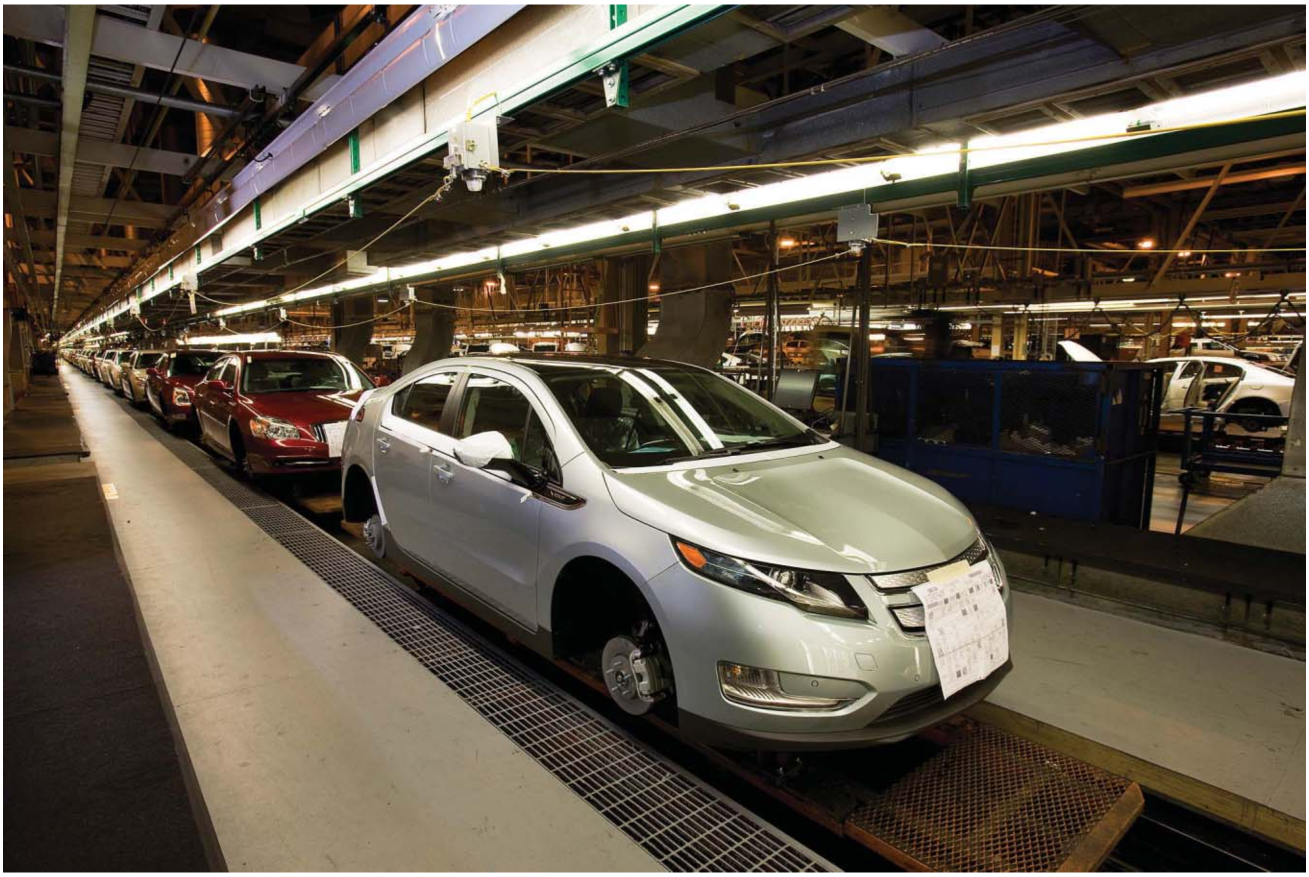


One Million Plug-in Cars by 2015?

Why nobody agrees on how many plug-ins will be on U.S. roads

SINCE 2008, Barack Obama has consistently promoted the goal of having 1 million advanced technology vehicles on U.S. roads by 2015. The number refers to plug-in vehicles that use grid power, stored in lithium-ion battery packs, to operate their electric traction motors. Regular hybrids like the Toyota Prius don't do that. The all-electric Nissan Leaf, the series hybrid Chevy Volt, and an upcoming plug-in hybrid version of the Prius do.

But recent analyses by experts and industry analysts differ sharply on whether that number is achievable. Many say that high cost, limited range, a nascent supply chain, and consumer hesitancy will make 1 million vehicles in five years impossible.

Advocacy groups, other analysts, and the U.S. Department of Energy insist the number is reachable—even if it may be a "stretch goal," in the words of market research firm J.D. Power & Associates, which considers 750 000 more reasonable.

In January, a panel of industry experts, convened by Indiana University, issued a 78-page report, *Plug-In Electric Vehicles: A Practical Plan for Progress*, that called the 1 million goal undoable. The panel based its conclusion on announced production volumes of plug-in vehicles and its own analysis of consumer demand.

Just days later, the DOE riposted with an 11-page status report, *One Million Electric Vehicles by 2015*. Its conclusion was different: Based on "conservative"

PLUG-IN PARADE: Preproduction Chevrolet Volts roll along the assembly line at a General Motors plant in Detroit. But how many will find a buyer?
PHOTO: GENERAL MOTORS CO.

update

estimates of production plans, it said, a total of 1.22 million plug-in vehicles could be built and sold by the end of 2015. The DOE report, oddly, sourced not automakers but media reports of their plans.

The DOE predicted that two-thirds of the 1.22 million could come from General Motors (with its plug-in series hybrid Chevrolet Volt) and Nissan (which sells the battery-powered Leaf and will add other models by 2015). It omitted estimates for hybrid powerhouse Toyota—which will sell a plug-in version of its Prius next year—and estimates from at least five other companies planning to sell plug-in cars.

Several points should be kept in mind about Obama's goal. First, it's cumulative over five years, not an annual sales rate. Second, it includes both retail buyers and fleet purchases. Third, 1 million vehicles in five years pales next to the 50 to 75 million new vehicle sales predicted in the United States over the same period—even more so against the 250 million vehicles on U.S. roads today.

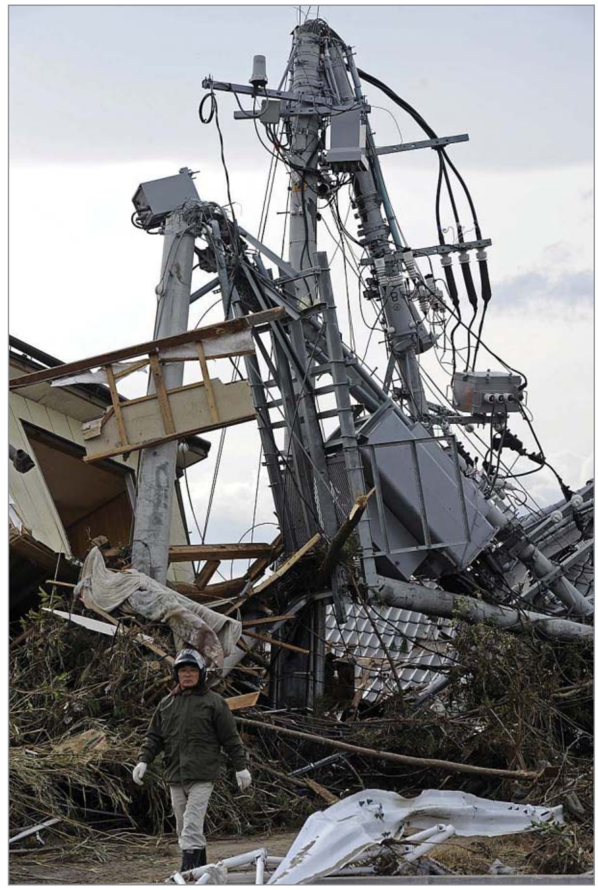
Finally, with U.S. corporate average fuel-economy standards set to exceed 30 miles per gallon (or fall below 7.8 liters per 100 kilometers) in 2016, automakers know they must start work on plug-in vehicles to prepare for the next round of even more stringent standards.

Analysts who say the goal isn't reachable cite three areas of doubt: supply, demand, and cost. Supply is easiest to analyze: Automakers rarely cite production targets, but estimates are leaked to trade journals or at industry events. Still, by most analysts' tally, global production of electric vehicles will clearly surpass 1 million by 2015. It's the number sold in the United States—a demanding market with very competitive pricing—that remains in doubt.

Consumer appetite for the vehicles is tough to gauge. Right now, the Leaf and the Volt are in high demand, with the earliest adopters proudly trumpeting cross-country trips in Volts bought many states away. The depth of the early-adopter pool is unknown, as is the degree to which a Volt or a Leaf becomes a rolling status symbol for some, as the Toyota Prius hybrid did in its day.

Many analysts, among them Rebecca Lindland, a director at IHS Global Insight, say one factor that will choke demand for pure electrics is that they'll never be capable of acting as a household's primary vehicle, given perpetual anxiety over their limited range (117 kilometers, or 73 miles, for the Leaf).

Working in favor of plug-ins is the fact that an average U.S. household now has more than two cars. Buyers mix vehicle types—sedans, minivans, sport utilities—to meet their different needs, and in years to come, they will likely do the same with power trains, say analysts and advocates. With 78 percent of U.S. vehicles traveling less than 65 km per day, not every vehicle has to be capable of more than the Leaf's 117 km.



PHILLIPPE LOPEZ/AFP/GETTY IMAGES

Japan's Earthquake and Nuclear Emergency

This issue was going to press when the 11 March earthquake and tsunami struck Japan. *IEEE Spectrum* editors and correspondents have been reporting news and analysis about the quake and its aftermath at http://spectrum.ieee.org/static/japans-earthquake-and-nuclear-emergency.

Cost remains the biggest deterrent. Plug-in vehicles today are far more expensive to build and buy than their liquid-fueled counterparts.

Early adopters eagerly pay more for goods they desire, but mainstream car buyers won't. That's the reasoning behind purchase incentives: They get more vehicles on the road sooner, bolstering the supply base. Even the \$7500 U.S. federal tax credit covers only part of that differential, though. Other state, local, and corporate incentives vary enormously.

Still, Oliver Hazimeh, a partner at management consultant PRTM, thinks there's untapped mainstream potential for plug-in cars. He says that the cars' advanced systems will "create a 'cool factor' "—especially among younger buyers.

Fleet buyers will help as well. Plug-ins would work well as urban delivery vehicles, because they could return to a charging depot at night. Still,

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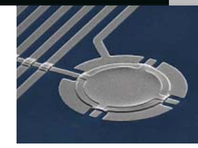


11 million times per second Frequency that microwaves drive the beat of a micromechanical drum built at the U.S. National Institute of Standards and Technology to demonstrate a principle of quantum mechanics.

according to Edmunds.com CEO Jeremy Anwyl, delivery vans of all sorts make up just 1.9 percent of the U.S. market.

But vehicle fleets aren't just commercial trucks. General Electric said in November it would buy 25 000 electric vehicles, including 12 000 Chevy Volts, for its own use. Plug-ins serve as rolling "green" ads for companies, but what all fleet buyers really treasure is the lower cost of running on grid power (it's one-fifth to one-third the cost per mile of gasoline).

That said, even automakers aren't convinced the United States will hit its 1 million target. Britta Gross, director of global energy systems and infrastructure commercialization for GM, thinks the country might miss the target by a year or two.

But whether the United States hits that mark in 2015 or 2017 may not really matter. Like the moon shot, an audacious goal has been put out there—and the industry is moving smartly toward it, which was hardly the case even five years ago.

The biggest determinant of whether Obama's goal will be met is oil prices. Unrest in oil-producing regions, plus growing demand from China, could convince consumers who are wary of gas-price levels to take the plunge—or more accurately, the plug.

—John Voelcker

Drawing Diodes

Engineers create semiconductor diodes inside optical fibers

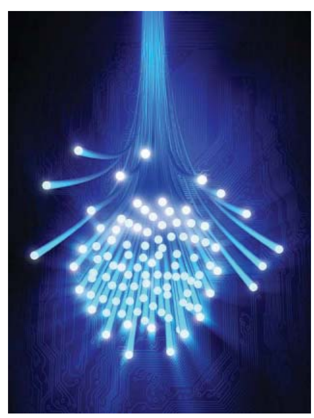
Materials scientists at MIT say they've found a way to build simple semiconductor devices inside a fiber. This new manufacturing process could create fibers with logic, image-processing, and photovoltaic capabilities that could one day lead to smart, self-powered fabrics, say researchers.

Nicolas Orf, a researcher in Yoel Fink's laboratory at MIT, managed to synthesize semiconductor materials into the precursor to an optical fiber, so that as the fiber is drawn out, the semiconductor forms into simple diodes with electrical contacts.

"You could end up with a piece of material that's a kilometer long," says Fink. "That's something that really could only happen if you can draw the materials."

Optical fiber is made starting with a thick, cylindrical boule of material—generally silica, although Orf and his colleagues used a polymer instead. The material is heated until it's soft enough to flow. Then it is drawn out into a fiber that's often hundreds of meters long but just a few micrometers in diameter.

Engineers have been intrigued by the idea of incorporating semiconductors into the fiber, but many useful semiconductors have high melting points and won't flow at the temperatures typically used in the drawing process. Fink's team got around this problem by using a multistep process. The researchers started by lowering the melting points of the components of the compound semiconductor zinc selenide—mixing the zinc with tin and the selenium with sulfur. They drilled slots along the surface of a solid boule of the polymer polyethylsulfone and inserted tin-zinc wires into the slots. They then used evaporation to deposit a thin



layer of the selenium sulfide on top of the wires and finally wrapped the whole thing with more polymer. This "preform" was then heated in a vacuum to produce a single, solid structure; it was then pulled into fiber.

As the tin zinc and the selenium sulfide were pulled close together during the drawing process, they underwent a chemical reaction, crystallizing into small chunks of zinc selenide, with tin wires providing electrical contact. The result was semiconductor diodes, the building blocks of many circuits, spaced at regular intervals along the length of the fiber.

"The fact that you can synthesize a high-temperature compound [the zinc selenide] inside a low-temperature matrix is very interesting and surprising, and as far as I know, this is the first time it has been demonstrated in the context of a fiber," Fink says.

The fiber drawing process essentially makes large structures much smaller and brings them closer together, so it should be possible to lay out fairly complex circuits in the preform to create nanometer-scale devices within the fiber. With the right reagents, Fink says, the process should work to produce a wide variety of semiconductor materials. That could make possible flexible electronic textiles and fibers that can convert light into electricity; perhaps one day a T-shirt could power a cellphone.

"These fibers open the door to intriguing possibilities," says John Ballato, an optical fiber researcher at Clemson University, in South Carolina. However, the use of polymers and soft semiconductors and metals may limit the amount of optical power that such a fiber could handle, he says. But the drawing method "can be considered an important step to a 'fiber that does everything'—creates, propagates, senses, and manipulates photons, electrons, phonons, et cetera."

—Neil Savage

A version of this article appeared online in March.

TOP: NATIONAL INSTITUTE OF STANDARDS AND TECHNOLOGY; BOTTOM: HENRIK JONSSON/ISTOCKPHOTO

10 million Number of Kinect units Microsoft sold between 4 November and mid-March. The gesture-recognition device is the fastest selling consumer gadget in history.

update

HYDROPOWER HORROR: Did a dam cause the Sichuan earthquake?
PHOTO: NG HAN GUAN/AP PHOTO

Earthquakes Hinder Green Energy Plans

Projects promising a cleaner atmosphere may be snagged by the subsurface rumblings they can cause

THE EXTRAORDINARY earthquake in Japan last month and the terrifying tsunami that followed left the country's electricity infrastructure crippled. But for some green technologies, the worry is not that they will be damaged by earthquakes but that they can *cause* earthquakes. Measured or anticipated seismic shocks associated with geothermal energy, hydropower, and carbon sequestration are raising questions about the wisdom of energy projects and in some cases stopping them in their tracks.

"We're observing earthquakes. People are feeling them. The people running projects are denying responsibility, and I don't think most people are buying it," says seismologist David Oppenheimer, project chief for the U.S. Geological Survey's Northern California Seismic Network. "It's foolish to go in with eyes closed."

Tectonic pressures cause the vast majority of earthquakes, but geophysicists also recognize the existence of human-induced seismicity. Hydropower reservoirs, for example, frequently cause small, shallow quakes as shifting water levels change the strains on the rock layers below. Such microseismicity—up to magnitude 4 on the Richter scale—is also caused by wells that inject hazardous waste and wastewater into deep rock formations at high pressure.

Microseismicity is merely an irritant, but human-induced seismicity can be deadly if it triggers the release of accumulated tectonic strain on a large fault. The textbook case occurred in 1967 when the filling of a reservoir behind India's hydroelectric Koyna Dam—completed six years earlier—unleashed a magnitude 6.3 quake, killing 180 people and leaving thousands homeless. Geophysicists continue to debate whether the Zipingpu Dam, completed in 2004, triggered the 7.9-magnitude earthquake that devastated China's Sichuan province three years ago, killing over 70 000.

In the United States and Europe, it's geothermal energy that's front and center as a source of induced seismic shocks. Draining hot-water reservoirs to generate power can induce shocks, as can reinjecting cool water to recharge the aquifer. The link to shocks is tighter still with enhanced geothermal systems, or EGS, whereby developers deliberately fracture hot rock formations with high-pressure water blasts to access geothermal heat.

Community backlash over microseismicity has stalled or killed leading EGS efforts in Europe. Officials in Basel, for example, canceled a promising EGS project after it set off a magnitude 3.4 quake in 2006, which revived awareness of a 14th-century temblor that leveled the Swiss city.

A similar story is playing out in the United States. EGS projects have multiplied there since a seminal 2007 report predicting that EGS could provide 10 percent of U.S. power demand by 2050—25 times as much as what geothermal now delivers. But getting EGS projects going has proved tough. AltaRock Energy, based in Sausalito, Calif., scrubbed exploratory EGS drilling at the Geysers, a geothermal hot spot north of

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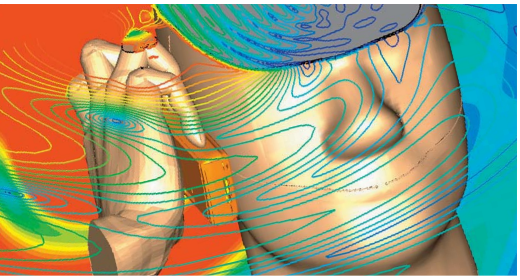

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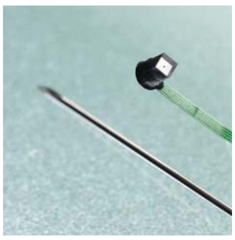


news brief

Disposable Endoscope
Engineers at the Fraunhofer Institute for Reliability and Micro-integration, in Berlin, have come up with a 62.5-kilopixel camera chip so small and cheap that it makes a disposable endoscope possible. And really, who would want any other kind? The 1-millimeter chip costs less to make thanks to a new method that allows the lens to be bonded to the chips while they are still attached to the wafer.

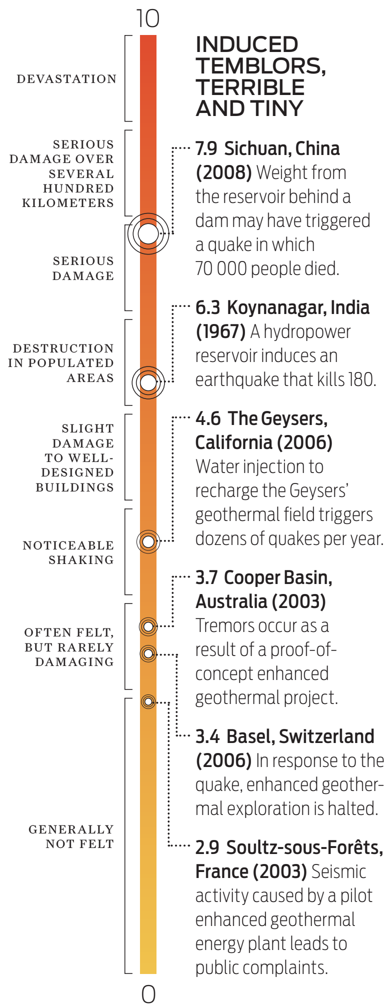
IMAGE: FRAUNHOFER INSTITUTE FOR RELIABILITY AND MICROINTEGRATION

San Francisco, after facing protests from residents and technical challenges with its wells. Northern California towns were already unsettled by continual microseismicity caused by conventional geothermal power plants built in the region since the 1960s.

Oppenheimer says geophysicists are in a poor position to reassure the public on the safety of geothermal production at the Geysers. He notes that the region is contracting as it cools—a rejiggering of geophysical strains that could trigger a quake of magnitude 6 to 7 on one of Northern California's large faults. The probability? "Unknown," says Oppenheimer, because "nobody has done the formal study."

EGS firms are beginning to assess risks. AltaRock, for example, released a seismic report in November for existing wells it hopes to start fracturing this summer on the flank of Oregon's dormant Newberry Volcano. The report asserts that the resulting shocks should be lower than magnitude 4, posing "more of a nuisance than a hazard" to the closest community, 14 kilometers away.

AltaRock needs to do still more, according to Ernest Majer, a geophysicist at the U.S. Department of Energy's Lawrence Berkeley National Laboratory. He is lead author on a protocol for managing risks that could become mandatory by June for federally funded EGS projects (including the work at Newberry). AltaRock's contractor, for example, based its estimate on shocks induced at the Geysers and other EGS sites—an assumption that AltaRock project manager Will Osborn defends as a "conservative approach," given the minimal seismic activity observed at Newberry. But ground movement is highly site specific, and Majer says that AltaRock should model induced shocks based on the subsurface conditions at Newberry before it moves forward.



Geothermal's teething troubles may foreshadow an even bigger problem for carbon sequestration, which governments worldwide see as a key strategy to control atmospheric levels of carbon dioxide. In recent months geoscientists have begun speaking out on the increased strain that millions of tons of CO_2 will place on subsurface rock formations. At the American Geophysical Union's annual meeting this past December, Stanford geophysicist Mark Zoback warned that even small earthquakes could crack the cap rocks overlying carbon sequestration sites, enabling the buoyant CO_2 to escape.

Modeling reported last fall by a U.S.-based consortium showed that concern was well founded for sections of the Mount Simon Formation, a rock layer spanning the U.S. Midwest that is a key target for CO_2 sequestration. According to lead researcher Mark Person, a hydrologist at the New Mexico Institute of Mining and Technology, fluid pressures from CO_2 injection in the formation's southern sections approach levels associated with earthquakes thought to have been caused by injecting hazardous waste into a well near Ashtabula, Ohio. Person says there is added reason for concern because the region has a history of massive earthquakes: The nearby New Madrid Seismic Zone delivered quakes with a magnitude of 7 to 8 in the early 19th century.

Person says carbon sequestration proponents need to anticipate and manage the risk of induced earthquakes, for example by injecting CO_2 at lower pressure. Failure to do so, warns Person, could be fatal to the whole endeavor. As Person puts it, "One big temblor, say a magnitude 6 earthquake, could shut the U.S. sequestration program down."

—PETER FAIRLEY

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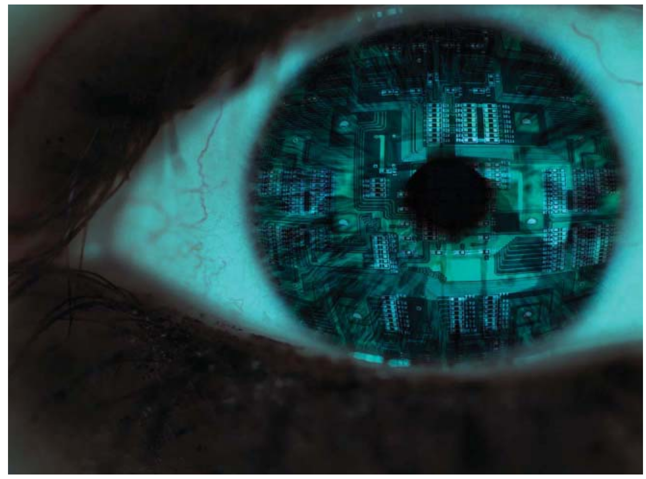
10 000 megawatts Shortfall in the Japanese electricity grid three days after the 11 March earthquake. Officials said power plants in western Japan could do little to help the stricken east.

update

The Sun's in Your Eyes

A solar-powered sensor could monitor the eyeball's pressure



DANIELLE TUNSTALL/GETTY IMAGES

IN THE FUTURE, that twinkle in your loved one's eye might be an implanted solar-powered pressure monitor. At the 2011 IEEE International Solid-State Circuits Conference in February, engineers from the University of Michigan, in Ann Arbor, described their work on a cubic-millimeter-size sensor meant to monitor pressure inside the eye. The researchers have yet to test the device in human eyes or animal ones, but they hope their system will one day thwart optic nerve damage brought on by glaucoma.

To determine a glaucoma patient's treatment, doctors must monitor pressure inside the eye, says Gregory Chen, a graduate student of electrical engineering at Michigan. Today's methods gauge that pressure by pushing on the cornea, the eye's clear outer coating. The results may be inaccurate: "If you just happen to have a really thick cornea, your eye is going to be harder, no matter what the pressure is," Chen says. The engineers' prototype device would allow a microelectromechanical systems (MEMS) capacitive sensor to record pressure from inside the eye about every 15 minutes and store it to static RAM. Once a day, the system would wirelessly transmit the day's data, via two on-chip inductors, to a wand. The inductors would send the data at both 400- and 900-megahertz carrier frequencies, as a means of mitigating the signal's noise and increasing its range.

Powering this daily transmission was one of the team's biggest challenges, says Mohammad Hassan Ghaed, the Michigan grad student who designed the radio system. "The common way of transmitting data is to use an external antenna," he says, "but in this millimeter-cubed space, we don't have that luxury." The team designed the diminutive device for easy implantation, but the small size comes at a cost: The device's inductors require more power to send data than a bigger antenna would, a peak of 47 milliwatts. That was a problem, given that the peak power supplied by their device's thin-film lithium battery is only about 40 microwatts.

To make up for this shortfall, the system stores enough energy to transmit one bit in a capacitor. The device then sends that bit and refills the capacitor from the battery for another go. The bit-by-bit method provides a transmission rate of around 10 kilobits per second, but with a day's data totaling around 1.5 Kb, it's still "near instantaneous," says Dennis Sylvester, a professor of electrical engineering, who led the team with colleague David Blaauw. The battery itself lasts around 28 days before it's drained, but the device also includes a miniature solar panel. The team expects that about 10 hours of indoor lighting or 1.5 hours of sunlight daily could recharge it.

"As far as I know, nobody does solar power at this size," says Pedro Irazoqui, director of the Center for Implantable Devices at Purdue University, who is also developing an implantable glaucoma sensor. Irazoqui praises the Michigan team for its energy-harvesting system and on-chip radios. His own team's tadpole-shaped device, which is now being tested in rat eyes, uses radio waves from an external source to power a 2.7-mm antenna "tail" for transmission and to charge an onboard supercapacitor.

Irazoqui's commendation of the Michigan device comes with some caution. "There are a lot of impressive innovations here," he says, "but until they've actually implanted it in a live eye and measured the pressure, they haven't shown that the device works." Of particular concern, he says, is that surgeons would need to implant the device in the "very delicate" iris tissue.

The Michigan team notes that human testing is still several years away. "Now that we have a system that is working, we can start to expand into long-term effects," Blaauw says, noting grad student Razi Haque's work to optimize the device's packaging in collaboration with Michigan professor and IEEE Fellow Kensall Wise.

What doesn't seem to be a concern is that staring into the wearer's eyes might reveal a speck of cyborg. "We're expecting to make different colors," Chen jests. "It's going to be a fashion statement."

—JOSEPH CALAMIA

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the big picture

OFF THE WALL

You didn't have to be in one of the 756 seats inside the new Frank Gehry–designed New World Center, in Miami Beach, to have witnessed the concert there on 28 January. Scores of music lovers, camped outside at the adjacent Miami Beach SoundScape, a 1-hectare gathering space, enjoyed the sounds of the orchestra while video of the New World Symphony's performance was projected onto a 650-square-meter wall. The high-fidelity audio simulcast came via 167 speakers mounted in an array of horizontal and vertical tubes that enhanced the sound.

PHOTO: MICHAEL MCELROY/THE NEW YORK TIMES/REDUX

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geek life

BOOK 'EM, OKA: THE "HAWAII FIVE-0" team gets an assist from medical examiner Max Bergman (Masi Oka).
PHOTO: NEIL JACOBS/ CBS/GETTY IMAGES

ACTING LIKE A NERD

Graphics programmer and "Hawaii Five-0" actor Masi Oka channels his inner geek

Masi Oka has reached cult status playing lovable but geeky social maladjusts on NBC's "Heroes" and more recently, on CBS's new "Hawaii Five-0." It's a role he knows well. When he isn't in front of a camera, he's in front of a computer writing visual effects or gaming code.

Since graduating from Brown University, where he majored in math/computer science and minored in theater arts, Oka has managed dual careers as a programmer and an actor. He spent years as a visual effects coder and consultant for Industrial Light and Magic (ILM) on such films as *The Perfect Storm, Terminator 3*, and *Pirates of the Caribbean*, and he is now developing a number of video games.

In the TV show "Heroes," Oka plays Hiro Nakamura, a shy Japanese office worker with an awkward but enthusiastic embrace of newfound superpowers. His supporting character on "Hawaii Five-0," medical examiner Max Bergman, is a hyperfocused, insular savant. So is he acting or just channeling his inner geek?

"I was one of those, too. I still am," he says, laughing. "I draw upon my own life and experiences, including using some of my professors as models. There's often a piece of me in those roles, especially ones I'm playing for years. I'm social but equally comfortable in front of a computer, which gives me a feeling of control. I think that's the current state of youth in America. They're used to communicating behind a wall now."

His comfort with computers also gives him a leg up in acting in front of a green screen, done when a scene's background will be edited in later. "I know what movements are going to save time and money in postproduction," he says.

Oka says that acting—especially in a comedy—is like computing, in that both allow him to be highly creative within a structured framework. "That's why a lot of comedy writers come from engineering backgrounds," he says.

After graduating in 1997, Oka landed a job at ILM's San Francisco headquarters. But he soon started going on acting auditions, even as he was helping to pioneer visual effects that weren't yet incorporated into Hollywood's primary programming language, Maya, such as computational fluid dynamics simulations for raging oceans.

"ILM let me pursue acting as long as it didn't interfere with my job," he says. "Most of my work involved writing programs. It didn't matter when I worked, just that I got it done on time. I didn't have too much of a social life, so I came to work at night or on weekends."

In 2000 he left ILM and moved to Los Angeles to pursue acting. Within three months, he ran out of money. "I thought, 'What can I do?' I didn't want to be a Web designer—I couldn't stand Web coding," says Oka, who doesn't tweet, blog, or have his own Web site. "So I started looking at local effects houses."

ILM caught wind of it and offered him work in its LA office, with the condition that if he didn't find acting work in a year, he'd return to San Francisco. By the following spring, Oka won a recurring role on an FX Network pilot. While the pilot didn't get picked up, it fulfilled the obligations of his contract. Oka went on to appear in TV's "Scrubs," "Will & Grace," and "The Gilmore Girls," and nearly a dozen films, including *Get Smart, Along Came Polly,* and *Austin Powers in Goldmember*.

Oka is also developing a science-fiction film for DreamWorks Studios and several video games for undisclosed companies. While he's been too busy to resume his normal programming duties for ILM, "I'm theoretically still an employee," he says. "So if any of my projects go, I can use my employee discount of 'buy two special effects, get one free.' " —Susan Karlin

A version of this article appeared on the Web in March.

A CAR THAT'S FASTER THAN A SPEEDING BULLET

British pilot Andy Green has already gone faster on the ground than most things go in the air. Now he's aiming for 1000 mph by 2012

ROAD SHARK: The Bloodhound SSC show car lies in wait at its home on the waterfront in Bristol, England.

PHOTOS: FLOW IMAGES

IN 1997, British Royal Air Force fighter pilot Andy Green broke the world land-speed record at 763 miles per hour (1228 kilometers per hour)—literally faster than some bullets. Now he's gunning for a new record in 2012—driving 1000 mph (1609 km/h) in the new Bloodhound supersonic car.

Getting there is tricky. A 30 percent increase in speed takes a lot more than 30 percent more power or strength. Loads and stresses increase by the square of the speed—power by the cube, says Green. So the main challenges were building a craft that could maintain control and stability at supersonic speeds, and engines that could produce enough thrust while keeping weight and air resistance down. There's a jet engine to accelerate the Bloodhound to 350 mph (563 km/h), and a rocket to boost it to 1050 mph (1690 km/h). The US $15 million project, led by British entrepreneur Richard Noble and funded by more than 300 sponsors, uses a computer at Swansea University, in Wales, with 128 parallel processors to analyze 100 million concurrent data points involving fluid dynamics and aerodynamics, and another three processors to monitor engine systems and controls.

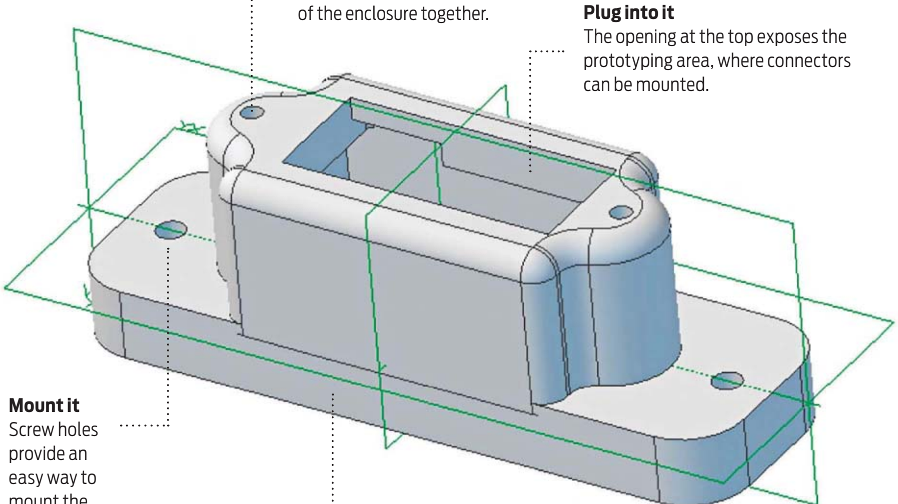
"We're doing things jet fighters can't do," says Green, who graduated from the University of Oxford in 1983 with a bachelor's in mathematics and has been on active Royal Air Force duty ever since. "For example, the wheels have to handle 50 000 *g*'s and 10 300 revolutions per minute."

The Paris-based Fédération Internationale de l'Automobile, official keeper of the world land-speed record, allows competitors—like the joint U.S./Canadian North American Eagle Project and Australia's Aussie Invader—to discuss their approaches with each other. (Another competitor, the Fossett LSR, is on hold. Its former sponsor, the American adventurer Steve Fossett, disappeared and presumably died in a plane crash in 2007.) "The only rules are that the vehicles have four wheels and be controlled by a driver," says Green. "Our vehicles are remarkably different, so we can share information with the competition." (Among the many differences, the Eagle is jet powered only, the Bloodhound has both a jet and a hybrid rocket engine, and the Invader uses a single liquid-fueled rocket motor.

While the Bloodhound project accelerates toward a 2012 summer test of 800 mph (1287 km/h), it also serves as an educational program that uses the physics, engineering, and environmental problems it encounters to teach math, science, and technology and inspire a new generation of scientists and engineers. The project is being followed by 4000 schools and colleges in the United Kingdom and in 202 other countries worldwide.

"The world is short of engineers," says Green. One goal of the project is to inspire a new generation of engineers. "Kids nowadays want to make money or be on reality television," he says. "How do you ignite interest at school level? This is what Bloodhound is trying to achieve." —SUSAN KARLIN

hands on



DAVID SCHNEIDER

THE SHAPE OF THINGS TO COME

You don't need a 3-D printer to get 3-D-printed parts

Most *IEEE Spectrum* readers are well aware of the declining cost of 3-D printers. Still, if you don't have the scratch for a US $15 000 desktop unit or the time to build yourself a RepRap, as Paul Wallich described in our January 2009 issue, you'll probably find owning your own unit out of the question. But as Wallich suggested in these pages in September 2010, there's a third avenue to 3-D printing that's easier and probably better: Shop out the work.

Those words may be anathema to hard-core do-it-yourselfers. To be sure, your fingernails will stay embarrassingly clean—the only tools you'll be picking up are calipers and some computer-aided design (CAD) software—but turning an idea into a physical object this way still involves some hands-on moxie, as I've recently discovered.

The abstract interest I had in 3-D printing became quite concrete when I needed an enclosure for a microcontroller. The one I was using—an Arduino Pro Mini from Sparkfun Electronics—is tiny and lacks screw holes, so there was no built-in way to mount it.

To start, I needed to acquire a serious 3-D CAD package. My first choice would have been SolidWorks—the software of choice for many mechanical engineers. But (ouch) licenses start at about $4000. While I'm sure the program is duly impressive, it's overkill for an occasional user like me. Lots of CAD software is available free for the downloading, but the ones I've tested proved far too crude for a project like this. So at a friend's suggestion, I acquired what appears to be the perfect Goldilocks solution: Alibre Design Personal Edition, which is plenty powerful enough for my needs without inducing sticker shock. It costs just $99.

It took me some time to get comfortable with the user interface, because rather than specifying the dimensions when you first draw something, you instead create only a very approximate shape. Then you add dimensions or constraints, at which point the program changes the shape to match whatever specs you set.

It also took me a while (and a visit to Alibre's online forum) to discover the real key to using the software—literally: the F5 key. Hitting F5 regenerates the object on screen with whatever changes you've lately made to its specifications.

Because the Arduino Pro Mini is so small, I decided to mate it with Sparkfun's matching prototyping board, which fits within the same tiny footprint. This would give me a place to mount connectors to the microcontroller, along with a few discrete components if need be. The prototyping board sits directly above the microcontroller, so the whole package remains quite compact.

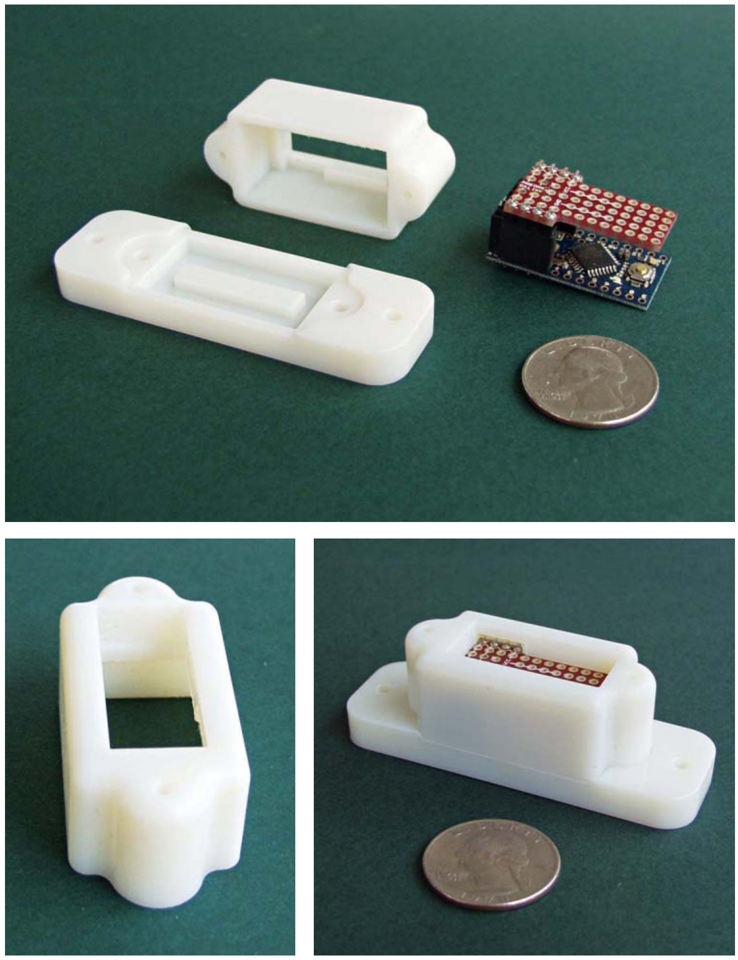
I designed the two-piece enclosure to have mounting tabs on the base, so it can easily be attached to any surface with a couple of screws. The base supports the Arduino board and includes space so that you can solder wires on without wrecking the fit. The enclosure is open at the top, allowing you to mount connectors to the prototyping board. This part of the enclosure also provides a feature I wouldn't know how to fabricate any way other than with 3-D printing: an inner support for the cantilevered prototyping board.

Following the carpenter's motto—measure twice, cut once—I went over the design carefully to check the interior dimensions against the physical boards before using Alibre's software to generate STL (stereolithography) files, the standard format used to specify 3-D objects for printing. A little probing on the Web revealed the great variety of processes that can be used for this, including fused-deposition modeling, selective laser sintering, and stereolithography. More online investigation with some of the vendors also revealed the great variety in cost. The quotes I received for fabricating my little enclosure ranged from $30 to $150.

Figuring that my first attempt would surely have flaws, I simply chose the fabricator with the best pricing, a company called FastProtos.com, located in Edmond, Okla., which uses a process called PolyJet printing. If the end product was of poor quality, I reasoned, at least I could test it out a bit before my next iteration with some other vendor or process.

The online transaction with FastProtos went as smoothly as buying a book from Amazon, and the enclosure came about as quickly—one week. I was wowed. The curved surfaces showed no awkward faceting, the base and top fit together snugly, and both were very clean, which I understand can't be taken for granted in 3-D printing. Even more surprising was that I hadn't flubbed the design: The stacked printed-circuit boards slipped right in with no discernible slop. So I ended up with a very slick enclosure right off the bat.

Was it worth $30? Ironically, it's the professional result itself that gives me pause—I'm tempted to compare it with the zillions of plastic doodads I buy off the shelf, in which case $30 seems rather steep for so small an item. But were I to be shown something of the same size and shape machined out of a chunk of nylon or Delrin, I would immediately declare $30 to be a great bargain. In any event, there's no question that fabricating highly engineered widgets is nowadays easy and cheap enough to be within anyone's grasp. —David Schneider



TINY ENCLOSURE: This two-part enclosure was designed to fit stacked microcontroller and prototyping boards [top]. A slim shelf inside one end of the cover piece supports the edge of the cantilevered prototyping board [bottom left]. The opening at the top of the assembled enclosure exposes the prototyping area, allowing connectors to be mounted there.
PHOTOS: DAVID SCHNEIDER

tools & toys

Me & My Oscilloscope
Tektronix is asking users for "educational, as well as short and noncommercial" videos about "the most amazing thing you've done with your Tektronix scope." Those not entering might still want to mosey over to the site and vote for their favorite videos.

The "Scopes, Camera, Action" challenge began 23 February 2011 and runs until 30 April. First prize is a Tektronix MSO2024 oscilloscope.

http://mytektronixscope.com

books

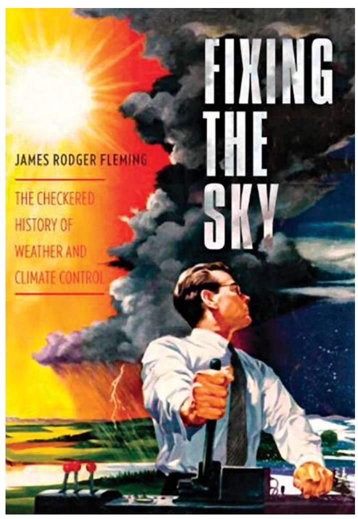
Civility of Climate

Weather modification, missile defense, acid rain—there's a lot going on in the sky besides climate change, and it's just as contentious

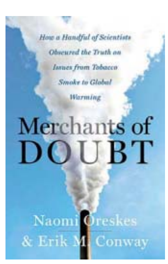
"THE TROUBLE with Americans," said Adlai Stevenson, a U.S. presidential candidate, in 1956, "is that they haven't read the minutes of the previous meeting." Naomi Oreskes and Erik M. Conway pick that statement as an epigraph to their book, *Merchants of Doubt*, but James Rodger Fleming, author of *Fixing the Sky*, might have chosen it just as well. Both books offer minutes to some of the contentious meetings in which science has collided with policy, and in so doing, they provide calming perspectives on some of today's raging debates.

Contrary to what you might infer from the titles, neither book is primarily about climate. *Fixing the Sky* is almost entirely about the history of weather modification schemes, while *Merchants of Doubt* mainly concerns missile defense, acid rain, ozone depletion, and secondhand tobacco smoke. But both books draw well-tempered conclusions about climate policy from those subjects.

Fleming talks disarmingly in his preface about how, after taking one flight too many into the eye of a storm, he gave up a budding career as a meteorologist for the safer world of science history. He immediately inspires confidence with what for my money is the most authoritative concise treatment of the pioneering climate theorists and experimenters of the 19th century—Fourier, Ekholm, Arrhenius, and Callendar.



Fixing the Sky
The Checkered History of Weather and Climate Control
By James Rodger Fleming; Columbia University Press, 2010; 344 pp. (hardcover); US $27.95; ISBN: 978-0-231-12412-4 (book); 978-0-231-51306-7 (e-book)



Merchants of Doubt
How a Handful of Scientists Obscured the Truth on Issues from Tobacco Smoke to Global Warming
By Naomi Oreskes and Erik M. Conway; Bloomsbury Press, 2010; 368 pp. (hardcover); $27.00; ISBN: 978-1-59691-610-4

What follows is a detailed and absorbing account of humankind's invariably unsuccessful attempts to modify and control the weather. His very civil but unexciting conclusion: Forget for now modifying something we don't understand well, and adopt a sensible global program of greenhouse-gas reduction and adaptation.

"Some have asked if the risk of geoengineering is worse than the risk of global warming," Fleming observes. "I think it just might be."

Essentially, the same moral would seem to follow from the case studies by Oreskes and Conway. Their message, in a nutshell, is that some scientists have made it their business to cast doubt on scientific findings that seem to imply the need for governmental action. What's especially disconcerting—at least in the debates over acid rain, ozone depletion, and climate change—is that it's been the exact same small group. That strongly suggests that its members are motivated not by expertise in the subject at hand but by ideological prejudice.

Oreskes and Conway do a good job of showing where skeptics have been getting their arguments, though they do not really explain the singular viciousness of the climate debate. But even so, here, too, there is much of interest to learn along the way. Some climate contrarians, for example, paint the Intergovernmental Panel on Climate Change as some kind of internationalist organization trying to foist its socialist ideas on the United States. Actually, say Oreskes and Conway, it was the brainchild of Robert T. Watson, a former Jet Propulsion Laboratory chemical kineticist who ran NASA's upper atmosphere research program. To borrow a trademark phrase from the late comedian Johnny Carson, I did not know that.

—William Sweet

A version of this review appeared on the Web in March.

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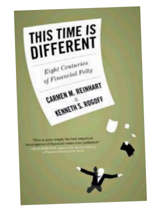

This Time Is Different
Eight Centuries of Financial Folly
By Carmen M. Reinhart & Kenneth S. Rogoff; Princeton University Press, 2009; 496 pp. (hardcover); US $35; ISBN 978-0-691-14216-6

Unlike other recent books on bubbles, this volume breaks new ground in providing a quantitative study of financial crises.

The authors show conclusively that such crises have occurred with high frequency and that the still-current economic crisis is in many ways typical in regard to how the bubble developed, how it crashed, how it is deflating, how it damaged the economy, and how most authorities refused to heed the plentiful warning signs, instead believing that "this time is different."

—Reviewed by Andrew Odlyzko

Read the complete review at http://spectrum.ieee.org/reviews technically speaking BY PAUL McFEDRIES

The Locavore's Dilemma

John Taylor [right] is tending Swiss chard, arugula, collards, spinach, turnips, and herbs this fall.... Located not in New Jersey farm country or even a suburban backyard, Taylor's farm project is brightening a fenced-in half acre in downtown Newark.
—Jennifer Weiss, *The Star-Ledger*

THE STAR-LEDGER, NEWARK, N.J.

FOR MANY readers, the spring has just sprung and the grass is riz, as the poet said. It's time, in other words, to turn our attention to growing things or, more to the point, to words related to growing things.

A column last year introduced some climate-friendly food terms, such as **foodshed**, the area where a person or family can obtain locally grown food; **food miles**, the distance that a food item travels from its source to the consumer; and **locavore**, a person who eats only locally grown food. (I didn't know it at the time, but it turns out that the spirited equivalent of the locavore is the **locapour**, a person who drinks only locally produced wine or beer.)

This obsession led to the *100-mile diet*, made up of only foods grown or produced within 100 miles of where you live. But why shoot for a 100-mile diet when you can be **hyperlocal** and strive instead for a **100-foot diet**, and reduce the **farm-to-fork** environmental costs of food by implementing a **garden-to-fork** strategy? In fact, why rely on a farmer at all? With a bit of pluck and a willingness to allow dirt under your fingernails, you can become an **urban farmer** who, despite the limitations of a city plot, grows much of his or her own food.

Edible gardening is the watchphrase of the grow-your-own-food movement, which is often called, pretty much inevitably, **grow-it-yourself**, or **GIY**. These backyard farmers engage in **SPIN** (from the phrase *Small Plot INtensive*) cultivation of vegetables and other crops. Many of these **SPIN gardens** (or **SPIN farms,** as they're sometimes called, with just a trace of irony) are as small as a quarter acre and sit in dense downtown areas. (So this practice just might qualify as **extreme gardening**, which refers to growing that takes place in hostile or difficult conditions.) Urban agriculturists who don't have a quarter acre to spare (or even a yard, for that matter) can still get in on the fun by **microgardening**, growing food in extremely small, dense plots, or even in a series of pots. (The artful arrangement of plants growing in pots and other containers is called **potscaping**.)

Big-city growers putting the "home" in homesteading are seen by some as **bioneers**, biological pioneers who are crafting local solutions to global problems. But bioneers can also be biological *engineers*, because they often resort to elegant technological solutions to the problems of growing crops within city limits. (I would be remiss at this point if I didn't mention the **pumpkineers** who grow giant pumpkins, particularly ones meant to be entered in pumpkin-weighing contests.) In the same way that gardeners have turned from *geoponics* (that is, growing plants in soil or a similar medium) to *hydroponics* (growing plants in water), today's urban homesteaders are practicing **aquaponics**, where aquatic animals are added to a hydroponic system to create a symbiotic environment; **bubbleponics**, where a highly oxygenated and nutrient-dense solution is applied directly to plant roots; and **aeroponics**, where plants are grown within a mist environment without any medium at all. If even misting is out of the question, city growers can turn to **xeriscaping** (also called **xerogardening** or **smartscaping**), where plants are grown using only minimal amounts of water, or even no water at all. ("Xeri" comes from the Greek *xeros*, meaning "dry.")

In the 1990s, some increasingly desperate and frustrated nutritionists began to use the term *food desert* to refer to an area, particularly an inner city, where fresh, healthy food is more or less nonexistent. Today, apparently even Newark, N.J., is turning into a veritable food oasis. If you grow the right crops and plan ahead for the winter, fresh, tasty, good-for-you produce can be had year-round. It might not feed the world, but it can feed your family—and make you a hyperlocal hero. ❏

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TOP 10 TECH CARS 2011

AFTER BEING PUMMELED by economic storms, the world's major automakers are bruised but still standing. You'd think they'd be playing it safe, but many of them are actually doubling down on technology, seeing it as the only way to seize a competitive edge and thereby avoid the fate of Pontiac, Hummer, Mercury, and other brands that went extinct because they couldn't keep pace.

As this year's top 10 list reveals, companies are continuing to pile their chips on electricity, hoping for a jackpot down the road. And decades from now, 2011 may well be remembered as the year when plug-in cars finally went mainstream.

Even with the first Chevrolet Volts and other plug-in models just trickling into showrooms, no one can yet predict how widespread their welcome will be. Regulations around the world may decree guillotine cuts in carbon emissions and leaps in fuel economy. But in the United States at least, the price of gasoline has been a far more reliable dictator of which cars and trucks people actually buy.

That means that the technological match is far from settled. One compromise solution, the so-called mild hybrid, seemed a dead end not long ago. But the advent of lithium-ion batteries and slicker electronic controls saw companies revive the mild bunch, so impressively that an example from Buick fought its way into our top 10.

As ever, high technology often means high prices, which explains the provocative presence of a certain Italian stallion, as well as a German racetrack beauty with an energy-scavenging device that recalls Doc Brown's flux capacitor in the movie *Back to the Future*. They're joined by a Japanese thingamabob that defies easy categorization, except for being the most affordable car here, reassuring evidence that hot technology eventually trickles down to the masses. —*Lawrence Ulrich*

FERRARI 458 Italia

This unashamedly internally combustive car showcases technology from the damn-the-expenses world of Formula One

As I GUN the Ferrari 458 Italia around a racetrack in the Catskills region of New York state, I get caught up in sheer sensation: The urgent, *braap-braap* shriek of its V-8 engine, the chest-squeezing *g*-forces as it rockets to triple the normal speed limit down the back straight, followed by whoa-Nellie deceleration to hospital-zone speed to negotiate a tricky uphill right-hand turn.

The seduction continues when I step from the cockpit to admire Ferrari's latest prancing pony, its carbon-ceramic brakes emitting waves of heat in the pits at the Monticello Motor Club. Even in shimmering repose, the 458 Italia—the successor to the estimable F430—pulls off a neat trick. It looks even more modern and technically advanced than the F430, yet also more beautiful.

It's plain to see why Luca di Montezemolo, Ferrari's chairman, was inspired to name this car after his homeland: The Italia plays up those sensuous Mediterranean curves, the classic Ferrari-ness that the company had sacrificed in recent years to remorseless function in supercars like the US $650 000 Enzo.

Although the Italia leaves casual admirers slack-jawed, its triumph ultimately comes from what's under that hubba-hubba skin: technology. Specifically, Formula One technology, developed in that cost-is-no-object racing series and now trickling down to the real world—well, as close to "real world" as a quarter-million-dollar supercar can be (although compared with the ridiculous $1.3 million Bugatti Veyron 16.4 or even the $375 000 Lexus LF-A, this Ferrari is a deal).

In contrast to Ferrari's front-engine, V-12–powered Gran Turismos, the Italia represents the more hard-core branch of the family: V-8 Berlinettas—two-seat, midengine coupes with intimate cockpits and track-ready performance.

Ferrari enlisted Michael Schumacher, the most successful driver in motor-sports history, with seven Grand Prix titles, to guide the transfer of Formula One technology to the street-going Italia. The company wanted to ensure that amateurs could safely explore the car's uncanny capabilities but didn't want to dumb down the thrills.

The Pininfarina-designed body manages to direct air for cooling the engine, gearbox, and brakes, while applying aerodynamic downforce and smoothing rear turbulence—all without an unsightly profusion of scoops or spoilers. Tucked discreetly inside the front air inlets, a pair of winglets deform slightly under air pressure at high speed to reduce drag.

Beneath that smooth shape lies an aluminum space-frame chassis, which includes extrusions originally developed for the aviation industry. Stiff

ALL PHOTOS PROVIDED BY MANUFACTURERS

and lightweight, the chassis helps the Italia to weigh in at barely 1380 kilograms (just over 3000 pounds), less than a Corvette or Porsche 911.

Behind the driver, the literal centerpiece of the car sits on glorious display beneath a clear cover: A flat-crank, dry-sump V-8 that generates 425 kilowatts (570 horsepower) and 540 newton meters (398 foot-pounds) of torque from just 4.5 liters of displacement. That's a new production-car record for both power- and torque per liter from a naturally aspirated engine.

The result is a street-legal race car that howls to 9000 rpm, reaches 100 kilometers per hour (62 miles per hour) in under 3.4 seconds, and keeps going to a top speed of 325 km/h. By that point the Italia is generating more than 3500 newtons of aerodynamic downforce, the equivalent of three NFL linebackers sitting on top and gluing the Ferrari to the pavement.

Inside, the dash contains Ferrari's first-ever digital displays, which allow the driver to adjust performance settings, audio, and navigation systems. The readouts have struck some critics as looking more Motown than Modena, but at least they work, if a bit awkwardly.

The fantasy continues with a straight-from-the-racing-pits steering wheel that houses critical controls, including the *manettino*, Italian for "little lever." That tiny switch adjusts settings for Ferrari's fearsomely complex F1-Trac stability system; its attendant E-Diff, an electronic, multiclutch rear differential, which monitors handling forces and allocates power between rear wheels; and an active suspension with shock absorbers that contain a magnetorheological fluid. That's a fluid that instantly changes viscosity when subjected to a magnetic field, providing adjustments to changes in the road surface.

The latest F1-Trac and E-Diff, Ferrari says, allow a driver accelerating out of a turn to apply 32 percent more force to the pavement than was possible with the F430 model. The seat of my pants doesn't argue: On Monticello's 6.6-km, 22-turn course, the Italia tangos on the knife edge of a skid, yet feels so poised that I'm encouraged to go faster.

Even turn signals and wiper controls are on the steering wheel: There are no control stalks—the one boy-racer element that seems gimmicky and awkward on public roads. But as I accelerate, LEDs trace the radius of that gorgeous wheel to alert me (if the banshee wail hasn't already) to that insane 9000-rpm redline.

That wheel also connects drivers to Ferrari's latest F1 dual-clutch, seven-speed gearbox. Operating on separate input shafts, one clutch operates even-numbered gears, the other odd-numbered. That means there's no interruption of torque to the wheels when the car lets go of one gear and grabs the next. This paddle-shifted plaything, notoriously clunky a few years ago, now operates smoothly, even in city traffic, and can burst into action with shifts in as little as 60 milliseconds.

Toggle the Ferrari's *manettino* into its racier settings and driving feels like a video game come to life, even if you stay in full automatic mode, which allows the Italia to sense and shift for itself. When I brake into the turns—the Ferrari's electronic brain knows they're coming—it rips off a series of neck-snapping downshifts, holding the gears at up to 8000 rpm to avoid unsettling the car through corners. As its signature three-outlet exhaust crackles and roars, it sounds so aggressive that I'm actually compelled to dial back the performance settings to avoid undue attention when driving on public roads.

There's only one real downer: No manual transmission is available. Some drivers, myself included, might still prefer an old-fashioned clutch pedal and shifter—and the physical involvement they afford.

But I appear to be in the minority. At the track, a Ferrari technical advisor suggested that only 2 or 3 percent of buyers would opt for a manual anyway. And so equipping the Italia would mean giving up the F1-Trac and gearbox, expensive goodies included in the price. (When I suggested offering a manual anyway and chopping $30 000 off the tab, the look I got said, "Silly American.")

I suppose if Michael Schumacher and Fernando Alonso Díaz can live without a manual transmission, so can Italia owners. Give the Ferrari credit for techno-wizardry done right: Italia drivers will have an unprecedented glimpse of what it feels like to be competing in Formula One. ❑

PORSCHE RSR CONCEPT

INSTEAD OF A BATTERY, IT USES A FLYWHEEL

Teenagers and tech buffs were equally agog at Detroit's auto show in January, where Porsche's 918 RSR concept was the pedestal-worthy smash. An orange-tinted cocktail of the 911 GT3 R racer and the upcoming, super-pricey 918 Spyder hybrid street car, the RSR incorporates the GT3 R's novel hybrid system to suck up braking energy and spit it back to the pavement.

Porsche calls the RSR its experimental race lab on wheels. Inside its rigid carbon-fiber monocoque structure, a V-8 engine develops 420 kilowatts (563 horsepower) at a heady 10 300 rpm, further juiced by a pair of 75-kW electric motors attached to the front wheels. Those motors can also provide torque vectoring to the front wheels, varying power to them independently to improve handling.

A bloated battery would be all wrong for this flyer. Instead, a flywheel accumulator rides shotgun next to the driver; this third fast-acting electric motor spins at up to 36 000 rpm to store power. It may not be much, but it's all on tap, all the time. The driver can exploit that bottled-up oomph by pushing a button and hanging on tight: The flywheel shoots its energy back through the motors, delivering an 8-second surge for exiting turns or overtaking a competitor. Consider it a nitrous-oxide boost but on a million-dollar budget. Hit the brakes into a curve and the electric motors attached to the wheels reverse function to generate electrical energy, which is then transformed back into mechanical energy in the flywheel.

As with Audi's high-mileage diesel racers, which have dominated recent 24 Hours of Le Mans races, the Porsche's efficiency could translate to fewer pit stops or smaller, weight-saving fuel tanks, thereby saving critical seconds. Porsche spokesman Dave Engelman notes that the system wouldn't be useful on family-focused models like the Cayenne. "There aren't many places on the street where you can even use 8 seconds of wide-open throttle," he says. But given a Porsche, a stoplight, and this magic button, it would be fun to try.

JAGUAR XJ

This jungle cat's muscles hang elegantly on a skeleton lighter than a Mini Cooper's

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I T'S NOT OFTEN that a car leaps several decades in one feline flash. But the Jaguar XJ, a hidebound symbol of the British Establishment since 1968, has been reborn as a modern showstopper. Conceived by Ian Callum, the former chief designer at Aston Martin, Jaguar's flagship is as sexy and athletic as anything in its full-size sedan class. With automakers looking to put cars on a diet to meet strict fuel-economy standards, the Jaguar's all-aluminum chassis and body makes it the class featherweight at barely 1860 kilograms (4100 pounds).

While I put the car through its paces, in Versailles, France, chief engineer Andy Dobson told me the XJ's chassis weighs less than the steel bones of the tiny Mini Cooper. Combine slender weight with an advanced V-8 engine—including 350- and 380-kilowatt (470- and 510-horsepower) supercharged versions—and the Jaguar is one ferocious cat, hitting 100 kilometers per hour (62 miles per hour) in 4.4 seconds. Keep sprinting to 240 km/h and the 350-kW XJ is a mere second slower than a Mercedes E63 AMG, a smaller, 386-kW supersedan. For a US $72 500 base price, the Jaguar will also brake from 110 km/h in less than 50 meters, matching a $140 000 Porsche Panamera Turbo.

The six-speed ZF transmission is an eager servant, and its unique rotary knob rises automatically from the console like the Armageddon button in a James Bond movie. Jaguar's continuously adaptive suspension reads the road surface 500 times per second, reducing body roll by 20 percent and helping the XJ to gobble curves like a British BMW.

Inside the posh cabin, the sound track for your adventure comes courtesy of a 1200-watt, 20-speaker Bowers & Wilkins system that tailors sound to each of four seating positions. A thin-film-transistor display screen replaces the traditional analog driver's gauges, to the dismay of Anglo purists. But switch into Dynamic driving mode and those gauges glow in a "red mist," while seat belts cinch occupants tighter for high-speed action. One bit of technology could use further grooming: The central infotainment touch screen is frustratingly slow and awkward. But that hiccup aside, the XJ ushers Jaguar into the 21st century with unexpected grace. ❑

BUICK LACROSSE

MILD, YES, BUT SATISFYINGLY FUEL-EFFICIENT, TOO

Compared with full hybrids like the Toyota Prius, yesteryear's so-called mild hybrids offered puny levels of electric assist in return for a modest price tag. But the half-hearted designs barely put a dent in fuel consumption, and the public rejected them.

Now, though, modern lithium-ion batteries have breathed life into the mild formula. Models like the Buick LaCrosse are the affordable result.

Indeed, it's so affordable that GM will add its new eAssist system as standard equipment to the four-cylinder 2012 LaCrosse this summer. That LaCrosse, a restyled version of Europe's Opel Insignia, will be priced identically to the V-6 model, starting at roughly US $30 000.

Like GM's original system, eAssist is mechanically simple: A belt-driven motor-generator links to the engine, replacing a conventional alternator. The system shuts down the 2.4-liter, 136-kilowatt (182-horsepower) engine at stops, and regenerative brakes capture energy that regular brakes would waste. But with a lithium-ion jolt, eAssist delivers more than five times the power boost—at a peak 11 kW and 107 newton meters (79 foot-pounds) of torque—and captures three times the braking energy of the previous nickel-metal-hydride battery system.

Just like that, LaCrosse becomes America's stingiest full-size sedan, at an estimated 9.4 liters per 100 kilometers (25 miles per gallon) on city streets and 6.4 L/100 km (37 mpg) on the highway. That's a 25 percent gain over the current four-cylinder Buick.

There's also no need to stuff the car with enormous batteries that exact a toll in price, performance, and mileage. The entire eAssist system, including the tiny 0.5-kilowatt-hour battery, weighs just 29 kilograms (65 pounds).

Other fuel-saving tricks include low-rolling-resistance tires and aerodynamic underbody panels. Shutters in the grille close electronically at higher speeds, further reducing drag. The result is a Buick that should save a typical owner more than $800 a year in gasoline compared with the V-6 version—without demanding a pricey technology investment up front.

NISSAN *Juke*

Cutting-edge automotive technology is generally costly. Here's a happy exception

AUTOMOTIVE HIGH TECHNOLOGY usually comes at a high price. That makes the Nissan Juke a cool splash of trickle-down tech: For less than US $20 grand to start, this endearingly geeky crossover—essentially a high-riding hatchback—is by far the most affordable car here. And though you won't find infrared night vision or other indulgences, the Juke amasses an impressive roster of gear for its diminutive size and price.

Nissan's new turbocharged 1.6-liter DIG (direct injection gasoline) engine spools up 144 kilowatts (188 horsepower) and an eager 240 newton meters (177 foot-pounds) of torque. That's mated to a continuously variable transmission, which maximizes acceleration and fuel economy. The car leaps to 97 kilometers per hour (60 miles per hour) in 6.8 seconds; it uses 8.7 liters per 100 kilometers in the city (27 miles per gallon) and does 20 percent better on the highway. Optional all-wheel-drive provides up to a 50:50 torque split between the front and rear wheels; it also incorporates a torque-vectoring system to boost stability and handling, a technology that until now had been limited to luxury cars.

True, Nissan's system isn't as sophisticated as the one from BMW: It automatically applies a single rear brake (on the inside wheel during a turn) to help pivot the car around a corner, rather than sending more torque to the outside wheel through a complex array of wet clutches and planetary gears. But a brake-based approach, also adopted by Ford on its 2012 Focus hatchback, gets the job done with less cost and mechanical complexity. Inside, cool details include a candy-apple-red center tunnel that recalls the Mini Cooper.

Performance recalls the Mini as well: The Juke is ideal for city denizens, with its shoebox size and taxi-baiting handling. Another welcome surprise is the optional six-speed manual transmission, something you won't find in cutesy Scion or Kia crossovers.

Nissan's I-CON (Integrated Control) is the final inspired touch. It appears just to manage climate controls, but press a switch and the backlit displays transform, allowing you to adjust throttle, steering, and transmission settings for Normal, Eco, or Sport driving. (Adjustable performance settings and dual-personality displays? What is this, an Aston Martin?) The I-CON screen even features fun little meters that show turbo boost or *g*-force loads—added entertainment when you're leaving rival crossovers in the weeds. ❑

FORD EXPLORER

CLEVER ENGINEERING BRINGS HYBRID-CLASS FUEL ECONOMY TO A GASOLINE-POWERED VEHICLE

Once the king of the American suburbs, the Ford Explorer was rudely deposed when buyers rejected primitive truck-based SUVs. Now the Explorer has been reborn as a car-based crossover. And if that's not heresy enough, try this: You can buy one with a four-cylinder engine instead of the model's former V-6 and V-8 guzzlers.

With seats for seven passengers, the Explorer's standard V-6 engine delivers fuel economy that's truly excellent for its size: 14 liters per 100 kilometers (17 miles per gallon) in the city and 9 L/100 km (25 mpg) on the highway. That's aided by a wind-cheating shape, variable valve timing, a six-speed automatic transmission, and fuel-saving electric power steering.

The Ford will save more fuel with that optional upcoming four-banger, a first in a full-size SUV. The EcoBoost engine

mates direct injection and turbocharging to deliver roughly 174 kilowatts (237 horsepower) and 339 newton meters (250 foot-pounds) of torque from just 2 L of displacement. And it's expected to deliver 8.4 L/100 km (28 mpg) on the highway, which would match Toyota's smaller Highlander Hybrid.

A new four-wheel-drive system incorporates a bit of artificial intelligence, letting drivers dial up settings for street, snow, sand, rocks, and more. And Ford's new Curve Control is the latest refinement of electronic stability-control systems: Head into a bend too quickly and the Explorer's sensors begin applying individual brakes and easing back the throttle, cutting speed significantly in less than a second. I found the Explorer's handling to be outstanding, easily matching far-pricier SUVs from Mercedes-Benz, Range Rover, and other brands.

The Explorer sports the first inflatable seat belts in a production automobile. Triggered by crash sensors, the tubular belts in the second row of seats fill with cold compressed air through a specially designed buckle. The belts spread crash forces over five times as much of the body as conventional belts, which is especially valuable for children or older passengers, who tend to be particularly vulnerable to chest, torso, or neck injuries.

Inside, the Sync system with MyFord Touch—codeveloped with Microsoft—allows voice or touch-screen control for phones, MP3 players, navigation, audio, and climate controls. Say your street address and bingo, it's set as a destination.

Yes, the badge still reads "Explorer." But this Ford is so modern, agile, and stuffed with technology that old fans will barely recognize it.

CHEVY *Volt*

GM unveils the highest tech of today's hybrids

AFTER TWO YEARS of awe and adulation, scoffing and skepticism—and with a General Motors bankruptcy and a federal rescue in between—the Chevy Volt has finally hit the streets.

And backing up a two-year PR spectacle that LeBron James would have blushed at, this plug-in hybrid turns out to be the potential game changer that Chevy promised. As expected, the Volt is a technical extravaganza. Featuring the world's most advanced hybrid drive system, it can and will deliver higher overall economy than any gasoline or diesel car sold in the United States.

But when I road tested the Volt, what really struck me is how ordinary it felt, and I mean that in a good way. This is a car that your computer-phobic grandparents could drive—and possibly fall in love with—without giving a thought to the liquid-cooled battery, planetary gears, and 10 million lines of proprietary computer code churning within. (A Boeing 787 Dreamliner, in comparison, makes do with 8 million lines.)

Nor will owners ever worry about driving range or places to plug in, something that can't be said for pure EVs like the Nissan Leaf, which must pause for multihour recharges after covering as little as 95 to 115 kilometers (60 to 70 miles). That's because the Volt offers a security blanket, a tiny 1.4-liter gasoline engine that generates electricity to power the car when the battery becomes too deeply depleted. So the Volt promises to usher in an era of electrified transport, while acknowledging that many drivers will still need to burn gasoline for longer trips.

After roughly 4 hours on its 240-volt home charger, the Volt's 16 kilowatt-hour lithium battery pack and dual electric motor-generators (let's call them motor A and motor B) propel the car for roughly 65 km (40 miles) on electricity alone. Driving especially gently, I actually managed 80 km. But go heavy on the gas or crank up the climate control and that range can plummet; the Environmental Protection Agency credits the Volt with a 35-mile electric range.

As Chevy notes, 75 percent of Americans commute 65 km or less round-trip. Those drivers could charge the Volt overnight and rarely burn a drop of gasoline. Install a charger at work

FISKER KARMA

BEHOLD THE MEGA-VOLT

If the Chevy Volt seems too tame, too utilitarian, another plug-in hybrid is looking to amp up the style and performance: the Fisker Karma.

Created by the Danish-born Henrik Fisker, whose previous designs include the lovely Aston Martin V8 Vantage and BMW Z8, the Karma is a luxury sports sedan in an eco-friendly mantle. Its visual drama and power will set you back a cool US $95 900 (before the federal or state tax breaks available to U.S. buyers). The Karma has been delayed many times; now it's supposed to reach dealers late this year.

Shown in final production form at the Paris Auto Show last October, the Karma's low-slung curves, 5.9-second sprint (in Sport mode) from 0 to 97 kilometers per hour (60 miles per hour), and 200-km top speed put it in a different league from the Volt. Yet it adopts the Chevy's range-extending approach and you'll double the daily range.

The Volt uses only about 65 percent of the capacity of its 16-kWh battery to ensure long cell life, which means that the car actually uses about 10 kWh. Recharging isn't 100 percent efficient, so a depleted battery draws closer to 12 kWh of electricity per charge.

The EPA says the Chevy returns the equivalent of 2.5 liters per 100 kilometers (93 miles per gallon) during all-electric driving. (That's using the EPA's formula, which equates 3.8 liters, or a gallon, of gasoline with 33.7 kWh of energy.) My own testing, however, puts it at an eye-popping 1.8 L/100 km.

Based on the U.S. electricity rate of 12 cents per kilowatt-hour, on average, the typical Volt owner will spend about US $1.50 to drive 40 miles, compared with the nearly $5 that the owner of a 25-mpg gasoline car will shell out.

When the Volt's 197-kilogram, 1.7-meter-long battery is 65 percent depleted, the car automatically enters its "extended range" mode. The near-silent gas engine begins providing energy for the front wheels in one of three modes: First, the Volt can operate as a series hybrid, generating electricity through its 55-kilowatt (74-horsepower) motor B. The larger, 111-kW motor A then uses that electricity to propel the car. At higher speeds, the Volt works more like a Toyota Prius or other conventional parallel hybrid, in which the engine not only keeps generating juice for the primary motor but also helps drive the wheels directly. In this case, the engine provides two-thirds of the motive power and the electric motor the remaining third. Finally, as with any hybrid or EV, the Volt uses regenerative brakes to help replenish the battery.

When I tested the Volt in its extended-range mode, relying on its smallish 35-L gas tank, it showed a hybrid-like 5.3 L/100 km (44 mpg), nearly 20 percent better mileage than its EPA estimate. Even figuring a conservative 6 L/100 km, the Chevy can deliver over 560 kilometers (350 miles) per tankful, in addition to those initial EV miles. Most critically, the Volt can then stop at any gas station, refill in five minutes, and keep cruising, just like the car you own today.

Mash on the gas, er, accelerator, and the Volt hums from 0 to 97 km/h (60 mph) in a reasonable 9 seconds, whether in battery or gas mode, and can reach 160 km/h. Handling is serene, if not sporty, and more nimble and confident than that of the Prius or the Leaf.

All told, the Volt delivered a combined real-world 3.6 L/100 km (65 mpg) when I averaged its electric and gasoline mileage, which is 30 percent better than a Prius, previously the nation's most fuel-efficient car. And that's based on a mere 50-50 split between electric and gas miles. Most owners, I suspect, will do better: They'll be striving to max out battery miles, avoid gas stations at all costs, and brag to the neighbors that they've gone cold turkey on Middle East oil.

Inside, this comfortable four-passenger hatchback offers an iPod-like center stack and interactive LCD screens, which coach drivers on how to maximize fuel economy. Smartphone applications let them remotely program charging times, receive alerts on charging status, and preheat or cool the car while it's plugged in, rather than wasting precious battery power once under way.

The Volt costs $40 280 to start, though a generous $7500 U.S. federal tax credit drops the freight to $32 780. And the Volt's sweetheart lease price of $350 a month—about half as much as the payments on a typical five-year loan—remains well within the reach of middle-class buyers.

Late this year, European buyers will find a spin-off model in showrooms: The Opel Ampera (or Vauxhall Ampera in the United Kingdom) is virtually identical to the Volt except for its sportier styling. And it will be interesting to see the reception to the Volt and Leaf in Europe, where drivers have endless choices in economy cars powered by clean diesels.

Although the Volt is frugal, owning one is not about saving money, at least not until economies of scale slash the cost of lithium-ion batteries. If saving dough is your sole criterion, you'd be better off with a five-year-old Honda Civic.

Certainly, the Volt is not for everyone, least of all people who see gas guzzling as an American birthright. But for early adopters and committed greens, or Americans who have come to view energy independence and conservation as a patriotic act, that old Civic can't touch the Volt.

And my hunch is that each time one of those buyers sails past a gas station, Chevy's pathbreaking new car will seem worth every penny. ❑

and even some GM hardware: A 2-liter, 193.8-kilowatt (260-horsepower) turbocharged Ecotec engine spins two powerful rear-mounted electric motors. Drawing from a 22-kilowatt-hour battery sitting below the floor, those motors send 300 kW and a brutal 1330 newton meters (981 foot-pounds) of torque to the rear wheels.

Fisker says his battery baby should deliver 80 km of all-electric range, following a 6-hour recharge on a 240-volt dock. As in the Volt, the gas engine is then tasked with generating current, allowing drivers to clock another 400 km before filling up or plugging back in.

Designing the car's curved solar roof proved a challenge. That photovoltaic panel can soak up enough rays to add 4 to 8 km of additional driving range per week, Fisker claims. The Karma also features an industry-first haptic feedback touch screen to control navigation, audio, and other key functions.

Tree huggers will demand the optional "Eco Chic" interior, with leather seats that use 85 percent of the cow's hide—scars, stretch marks, and all—and wood trim from reclaimed forest-fire timber, sunken logs, and other guilt-free sources.

The Karma is to be made in Finland, and Fisker hopes to build more than 100 000 cars per year. Orange County, Calif.–based Fisker and another California dreamer, Tesla, have together scored $1 billion in Department of Energy grants on the condition that they use it to develop lower-priced, made-in-America models. To that end, Fisker has secured a mothballed Saturn plant in Delaware—clearly imagining a brighter future than the one decreed for that now-defunct GM brand.

MERCEDES-BENZ

B-Class F-Cell

It runs on hydrogen, which packs more energy per gram than gasoline

IT SEEMS THE ultimate quixotic quest: a car that runs on hydrogen, a clean, endlessly renewable fuel, with water vapor its only by-product. But from Mercedes-Benz to Honda to General Motors, a corps of true believers has continued to tinker away, convinced that hydrogen-fuel-cell cars will find their way to showrooms, and sooner rather than later. These engineers and scientists are equally convinced that when Earth's oil grows scarce, hydrogen will become a dominant fuel to keep people and goods circling the globe.

You can count Vance Van Petten among the believers. In December, the Los Angeles resident became the first American to take the keys to a Mercedes-Benz B-Class F-Cell. He's one of only 200 people in California and Europe who will lease this rare hydrogen-powered hatchback for two years of beta testing.

Van Petten is an environmental advocate, who as executive director of the Producers Guild of America backs strategies to reduce the carbon footprint of film and television productions. He's now paying US $849 a month, which includes unlimited hydrogen fill-ups, to drive the F-Cell, now parked alongside his Ford Escape Hybrid.

He's already enamored of his F-Cell for its clear evidence of the Mercedes obsession with detail and safety, for its nearly 400 kilometers (250 miles) of driving range, and for hydrogen's squeaky-clean potential.

"I've been reading about fuel cells for years and was delighted to find that Mercedes was making one," Van Petten says. "I've lived with smog all my life, and cars have a huge impact on that."

Like other fuel-cell vehicles, the Mercedes (based on the company's conventional B-Class hatchback) generates electricity on board from a chemical reaction of hydrogen and oxygen to form pure water vapor. And unlike the overstuffed hydrogen cars of just a few years ago, it fits all the drive components neatly into a compartment below the cabin, called a sandwich floor; that way, they're safeguarded from collisions and don't intrude on interior space.

The components include the fuel-cell stack, three pressurized storage tanks that each hold 3.7 kilograms of hydrogen at 690 times atmospheric pressure, an electric motor that sends 100 kilowatts (136 horsepower) and 290 newton meters (214 foot-pounds) of torque to the front wheels, and a small 1.4-kilowatt-hour lithium-ion battery.

PORSCHE CAYENNE S HYBRID

DECOUPLE THE ENGINE—AND "SAIL"

Call it the prodigal Porsche. The Cayenne, once a shameless SUV guzzler, has returned, this time as a hybrid. It's still plenty fast and agile, but with a reduced appetite for unleaded.

Every 2011 Cayenne, including a striver's-choice V-6 gasoline model, which starts below US $48 000, benefits from the redesign. The body is toned and taut, and a plush new interior, inspired by Porsche's Panamera sedan, finally gives you the luxury you'd expect at such high prices.

The Cayenne S Hybrid's goodness is grounded in that redesign: Porsche trimmed nearly 180 kilograms (400 pounds) across the lineup—enough to balance the gear it had to add to make the car into a hybrid. The company eliminated the low-range, off-road gearbox that most drivers never used, slimmed the chassis, body panels, and power train, and used more aluminum and composites.

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Compared with the earlier, A-Class F-Cell, which has undergone trials since 2004, the system is 40 percent smaller and 30 percent more powerful, consumes 30 percent less fuel, and has more than double the driving range. Cold-start capability, once a tricky issue, is now down to −25 °C, thanks to a humidification system with hollow fibers that prevents water from freezing in the fuel-cell stack. In another advance, special seals on the tanks prevent the loss of any hydrogen—a particularly gaseous gas, by far the hardest to contain. The seals work even if the vehicle sits unused for long periods.

Hydrogen's advantages are inarguable, said Sascha Simon, manager of advanced product planning for Mercedes-Benz USA. When the gas is compressed, its energy density is about 300 times that of today's best lithium-ion batteries, and three times that of gasoline, itself a notably energy-dense fuel. And the fuel cell's thermodynamic efficiency—its ability to convert energy into mechanical work—is roughly 90 percent, more than double that of the best diesel internal-combustion engines.

Unlike an EV, a fuel-cell vehicle has a range undiminished by cold weather. More important still, it isn't saddled with huge, hefty, and relatively inefficient batteries. Compare the F-Cell's tiny 1.4-kWh battery, used mainly to capture energy from regenerative braking, with the 408-kg, 53-kWh monster that drives the two-seat Tesla Roadster.

Because of that insurmountable battery burden, pure EV technology (as opposed to gas- or diesel-electric hybrids) is currently unfeasible for pickups, SUVs, cargo haulers, or mass transit. Fuel cells, however, can easily be scaled up: Mercedes already combines two F-cell systems to power city buses. Yet Simon notes that the F-Cell is ultimately an electric car and that every technical advance in EVs, from motors to software, will lift all boats and bring fuel cells closer to reality.

"I want everyone to drive an electric car," he says. "But as a company that also builds trucks, we have to look at technologies that can power more than a small, city-sized vehicle."

Problems remain. While automakers have swiftly cut costs—from roughly $1 million per car a few years ago to perhaps the low six figures today—those costs continue to pose a chicken-and-egg challenge. To get the required economies of scale will require far more customers than this technology has attracted yet.

Also, although hydrogen cars can refuel in minutes rather than the hours that battery-powered cars need, there aren't a lot of places that can fill them up. The electrical grid already blankets every corner of the developed world, making recharging EVs straightforward, but there is essentially no infrastructure for creating and distributing mass quantities of hydrogen and dispensing it to drivers.

Mercedes-Benz is among the automakers that belong to the California Fuel Cell Partnership, which is laying the groundwork for a commercial hydrogen network. The Los Angeles area has about 16 hydrogen filling stations, the most in the world, according to the partnership. Another handful are currently planned, including in the San Francisco Bay area.

Home fueling is a possibility. To run its own hydrogen-powered FCX Clarity, Honda is on its fourth generation of what it calls a Home Energy Station. The system uses a natural gas line and steam to form hydrogen, supplying the vehicle while the station's own fuel cell provides home heating, hot water, and electricity, dramatically trimming household energy costs and carbon emissions. Honda has also developed a compact solar station that could electrolyze hydrogen from water.

Far from home, the perky Mercedes hatchback embarked on the F-Cell World Drive in January, its aim to circumnavigate the dry parts of the globe, spanning four continents in 125 days. That tour is meant both to demonstrate the viability of fuel-cell cars and to beat the drum for a refilling network.

Van Petten is doing his part. At a fenced-off Shell dispensary in Culver City, Calif., he punches codes to gain entry and to operate the pump. He's not sure who else uses it, or for what vehicles. Although it's in LA County, the dispensary is a bit out of his way. But to him it's well worth it.

"People complain that the technology is not convenient or too expensive," Van Petten says. "But I think it's our duty to invest in green technology and share the burden. Because if we don't, the Earth is going to kick us in the butt." ❑

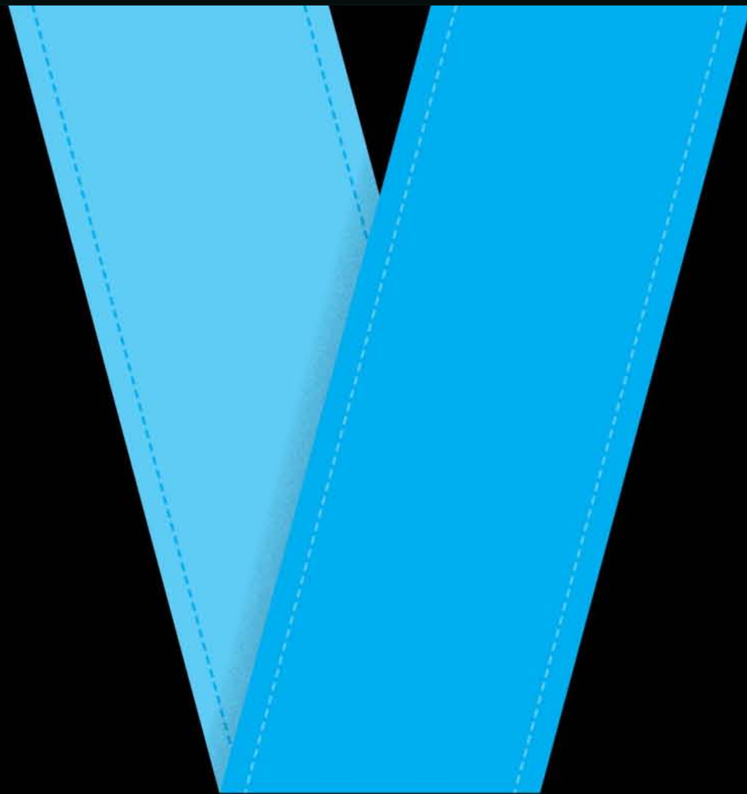
The $68 675 hybrid sandwiches a 35-kilowatt electric motor-generator between a supercharged, 248-kW V-6 and a fuel-saving eight-speed automatic transmission. Below the cargo deck is a tidy 288-volt nickel-metal-hydride battery.

The upshot is 289 kW and a burly 579 newton meters of torque, with peak torque on tap at just 1000 rpm. I breezed to 97 kilometers per hour (60 miles per hour) in a 6.1-second burst, 1.3 seconds quicker than it would take in the V-6 model, and only a half second behind the thirsty V-8 version. And the rear torque-vectoring system and Porsche's active suspension management together noticeably improve cornering.

But Porsche's hybrid twist is an electric clutch between the engine flywheel and electric motor, which can decouple the engine from the transmission. That boosts electric scavenging from the regenerative brakes and lets the car coast with its engine off—Porsche calls it "sailing"—at up to 156 km/h.

I managed to sail only at speeds below 120 km/h, though; any faster and the engine would come back online. Still, the results were evident: The U.S. Environmental Protection Agency rates the Cayenne at 21 miles per gallon (11.2 liters per 100 kilometers) in the city and 25 mpg on the open road, but I whipped those numbers. Going easy on the throttle, I kept the Cayenne at 7.8 L/100 km on the freeway, remarkable for this 2200-kilogram SUV. Even at a 120-km/h cruise, I saw 8.7 L/100 km. City miles returned a healthy 10.7 L/100 km, aided by the Porsche's ability to cruise short distances on electricity alone.

Expect to see more automakers adopt similar hybrid decoupling systems, as a virtually free-lunch way to save fuel.



COGNITIVE-RADIO GAMES

As our radios get smarter, they'll be competing for over-crowded airwaves. Game theory can make them cooperate

BY K.J. RAY LIU

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Steve Jobs was unveiling the iPhone 4 at Apple's worldwide developers conference in San Francisco last June when disaster seemed to strike. Jobs found he couldn't connect to the conference center's Wi-Fi network. Fortunately, his technical team rapidly pinpointed the problem. "We figured out why my demo crashed," Jobs announced to the audience. "Because there are 570 Wi-Fi base stations operating in this room. We can't deal with that."

Jobs then exhorted the crowd to free up the airwaves so that he could continue. "All you bloggers need to turn off your base stations. Turn off your Wi-Fi. Every notebook, I'd like them down on the floor." Most complied, but some refused to sever their wireless links, causing a sluggishness in connectivity that continued to dog Jobs during his presentation.

The incident was just a minor blip in the life of Apple. But suppose you had been a tech reporter whose livelihood depended on being able to send out real-time descriptions of events like this. Suppose further that nobody else would have known whether you were using a wireless base station. Would you have done as directed and turned off your gear? Why not stay connected? After all, one blogger, no matter how fast his fingers, wouldn't have slowed network traffic perceptibly.

The problem, of course, is that the same logic applied to everyone else in that room. And if all those hundreds of Wi-Fi base stations had remained on, Jobs wouldn't have been able to present the demonstration everyone was so eager to see.

The basic conundrum can be distilled into a simple—albeit not very realistic—game. Suppose you are one of only two reporters present. Imagine that if one of you stays connected, Jobs can still carry out his demo, but if you both ignore his urgings, everyone's Wi-Fi will completely cut out. You and the other reporter cannot communicate with each other. You just have to pick a course of action and stick to it. What's the smart thing to do?

Let's say your counterpart complies with Jobs's edict and powers down. In this case, you are clearly better off staying connected. Jobs will demo the new iPhone, and you can instantly report about it to the world, earning you fame and fortune.

Now let's say the other reporter ignores Jobs's directions while you comply. He will scoop you, making you the laughingstock of the newsroom when you get back to the office. So here again you're better off ignoring the instructions.

The logic is inescapable: No matter what the other person does, it's better for you to act selfishly. But the other reporter will surely come to the same conclusion, so you will both miss the demo. Why didn't the two of you cooperate?

What I've concocted here may be thought of as a wireless-networking version of what long ago came to be called the prisoner's dilemma, which depicts this same basic conflict in terms of two suspects in a crime, each of whom may (or may not) try to pin guilt on the other party. The prisoner's dilemma is commonly used to illustrate the rudiments of game theory, a branch of mathematics that analyzes not games like chess or checkers but the possible actions of intelligent—and potentially deceitful—adversaries.

Game theory was almost unknown before 1944, when mathematician and computer pioneer John von Neumann, then at the Institute for Advanced Study, in Princeton, N.J., and Oskar Morgenstern, an economist at nearby Princeton University, published *Theory of Games and Economic Behavior*. Their work was soon applied well beyond the boundaries of economics—in particular, to nuclear weapons policy during the Cold War.

Although the world's superpowers are no longer flirting so closely with mutually assured nuclear destruction, game theory remains as relevant as ever to various conflicts of modern life—including conflicting uses of the electromagnetic spectrum. Game theory is especially timely in that regard, because soon the parties squabbling over use of the airwaves won't just be individuals or companies. In the very near future, our radios themselves will contain so much intelligence that they will be battling one another for access to chunks of the wireless spectrum.

The kind of communication I'm talking about here falls under the umbrella of cognitive radio. That term refers to intelligent systems of wireless communication in which the radios people carry around try to achieve the best performance possible by sensing and adapting to changes in their electromagnetic environments, including changes in the way other radios are operating.

Regulatory bodies such as the U.S. Federal Communications Commission (FCC) are just beginning to embrace the idea of cognitive radio, recognizing that the traditional way they have assigned fixed portions of the spectrum is hopelessly inefficient. It's inefficient because whoever holds the license to broadcast at some assigned frequency doesn't actually use that privilege everywhere or at all times. Yet nobody else is free to use that frequency even when it's wide open.

ALL ILLUSTRATIONS BY JAMES PROVOST

The upshot is that radio spectrum, one of the world's most valuable resources, is mostly wasted.

Policymakers and engineers both want to develop systems that would let people take advantage of otherwise unused parts of the radio spectrum without creating chaos for license holders or themselves. One scheme under consideration, for example, seeks to exploit fallow TV spectrum—known in the trade as white space—for what some have dubbed "Wi-Fi on steroids." That certainly sounds attractive, but unless it's done with care, the people trying to use such networking equipment may end up with the same kind of frustrations Jobs experienced last June, only on a catastrophic scale.

The question of how best to share limited radio spectrum has mostly been studied from the perspective of whoever is calling the shots—say, a wireless carrier like Verizon or AT&T. How, for example, should each cellular base station divide up the airwaves it controls among the different customers it's communicating with? Such questions are comparatively easy to answer, because the base-station equipment can divvy up the available spectrum in whatever way the system designer specifies.

The up-and-coming world of cognitive radio will be a lot more complicated, because usually there will be no central authority. And you can't take for granted that different radios will harmoniously manage their operations so that they don't step on one another's transmissions. Indeed, a better bet is that they will act as selfishly as they possibly can.

Rational participants in any conflict for resources will always act selfishly

Regulatory authorities like the FCC may demand that these radios be programmed to act cooperatively. But in the end, it would be nearly impossible to police exactly how each person uses his or her cognitive-radio handset or wireless network adapter. Game theorists are not put off by such realities. Rather, they assume that rational participants in any conflict for resources will always act selfishly and will cooperate only when it improves their own chances of getting whatever it is they want.

Using game theory, my students and I recently devised some clever ways to foster cooperation among cognitive-radio users. There are many variations on this general approach. Which one you use depends on the details of the wireless network you are considering, how you measure success, and the means you have at your disposal to get everyone to play nice. Here I describe one example that's easy to understand without so much as a single equation.

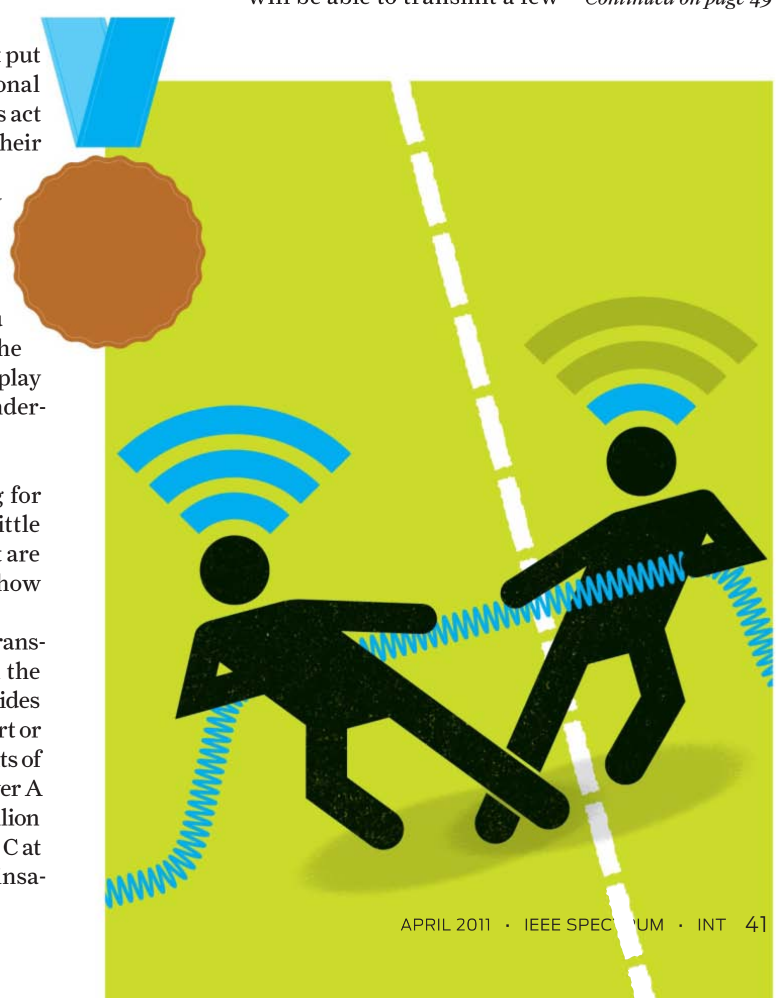
Let's say three pairs of radio users are vying for the same slice of the electromagnetic pie. In this little game, each "player" is really a pair: two entities that are exchanging digital data wirelessly. The details of how they do that don't really matter.

Imagine that each of these three players is able to transmit data at different rates because of differences in the condition of the radio channels used. Maybe the two sides of each player pair are located different distances apart or perhaps the three players experience different amounts of radio noise. To keep things concrete, let's say that player A can (in the absence of other players) send data at 10 million bytes per second, player B at 5 million B/s, and player C at 1 million B/s. Assume also that each player has an insatiable hunger for wireless bandwidth—which isn't all that different from real life.

The simplest cooperative strategy you can imagine is for these three players to graciously take turns: Player A uses the airwaves for some period of time (to keep things simple, assume it's 1 second); then B communicates for 1 second; then C transmits for 1 second; and then the turn passes back to A. Although the three players get equal airtime, networking specialists call this allocation *proportionally fair*, because the number of bytes they get to transmit in each second—a direct reflection of the bandwidth they are allotted—is not equal. Rather, the amount of data transmitted is proportional to the quality of their communication channels.

Arranging for all three to get equal bandwidth would be another way to share the available radio spectrum. But equal bandwidth wouldn't be such a great goal to strive for, because to achieve it, you'd have to give most of the airtime to the player with the slowest connection, which squanders the radio resource available to the group. Better to divide wireless privileges into brief time slots of equal duration and allot those one after another in turn to each of the three players.

The problem with using such a simple round-robin is that the conditions of radio channels are constantly in flux—a phenomenon that anybody who has ever used a cellphone in a building can attest to. Player A may be able to transmit 10 million B/s on average, but during certain seconds it will be able to transmit a few *Continued on page 49*



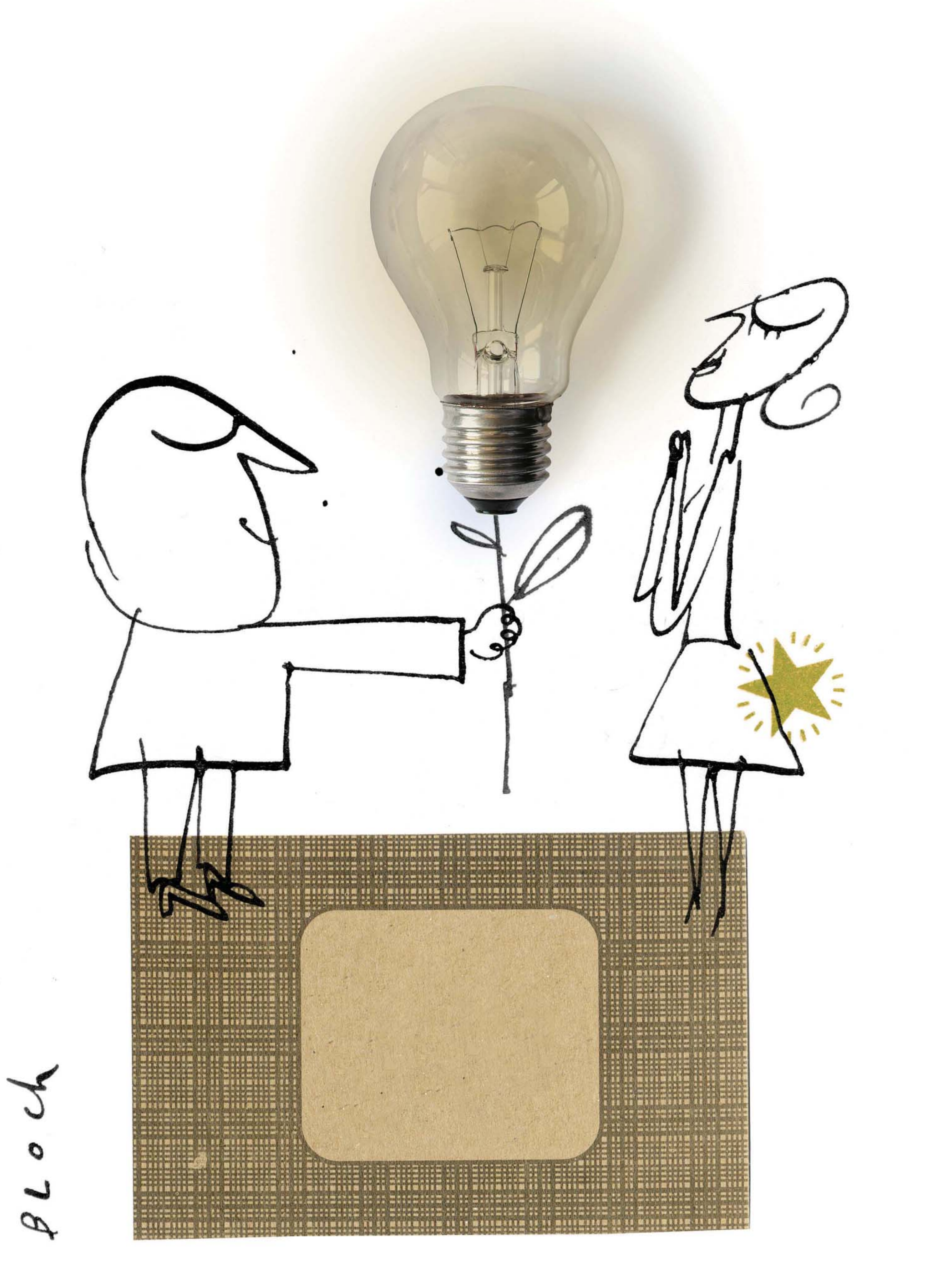
lights out

The end of an incandescent affair

BY BRIAN BOWERS

After a reign of more than 130 years, the incandescent lightbulb has earned a spot in the pantheon of the most successful technologies humankind has ever produced. It casts its glow in homes, businesses, and societies that would be almost unrecognizable to those who first delighted in its rays, like tiny suns in graceful glass. Along with the landline telephone and the internal combustion engine, it underpinned and helped usher in our modern world. And now, it's going.

SERGE BLOCH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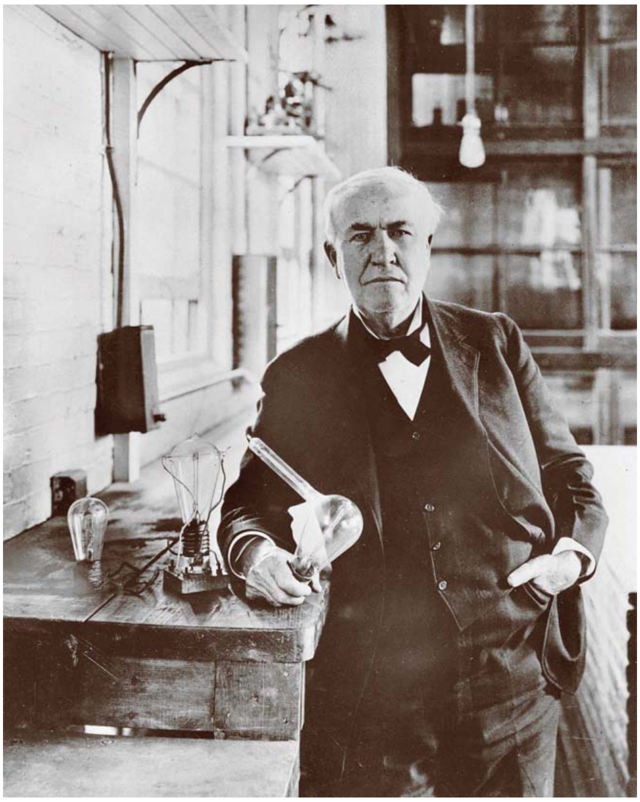


BULB BONANZA: When the means of creating a vacuum in a glass bulb were developed around 1870, lamp research took off. Thomas Edison [above, 1883] produced a lamp with a carbon filament made of bamboo fiber [top center, 1879]. Independently, Joseph Swan made a similar lamp with a cotton-based filament [top right, 1879]; a few years later the two teamed up to market the Edison-Swan lightbulb [right].

CLOCKWISE FROM LEFT: BOYER/ROGER VIOLLET/GETTY IMAGES; SSPL/GETTY IMAGES (3)

Brazil and Venezuela began abandoning incandescent lighting in 2005. Europe started taking traditional incandescent lightbulbs off store shelves in 2009. In the United States, California set standards that eliminated the traditional 100-watt incandescent this year, and the rest of the country will follow next year, with less-powerful incandescents falling like dominoes as stricter energy standards phase in.

We love the warm spectrum of the incandescent, but we're not so happy with its energy use. A typical 60-W bulb has an overall luminous efficacy of about 15, meaning that it radiates roughly 15 lumens per electrical watt consumed. In contrast, a comparable compact fluorescent would score about 65, and white light-emitting diodes (LEDs) approach 100. Even if you're not particularly worried about global climate change, the needless electricity expense should give you pause.

Nevertheless, many folks surprisingly cling to the mellow yellowish glow, refusing to go gently into an LED-lit night. In Germany, Austria, and a few other European countries, a curious phenomenon, incandescent-bulb hoarding, began in 2009. Californians, too, raced to grab the last of the available 100-W incandescents off the shelves earlier this year.

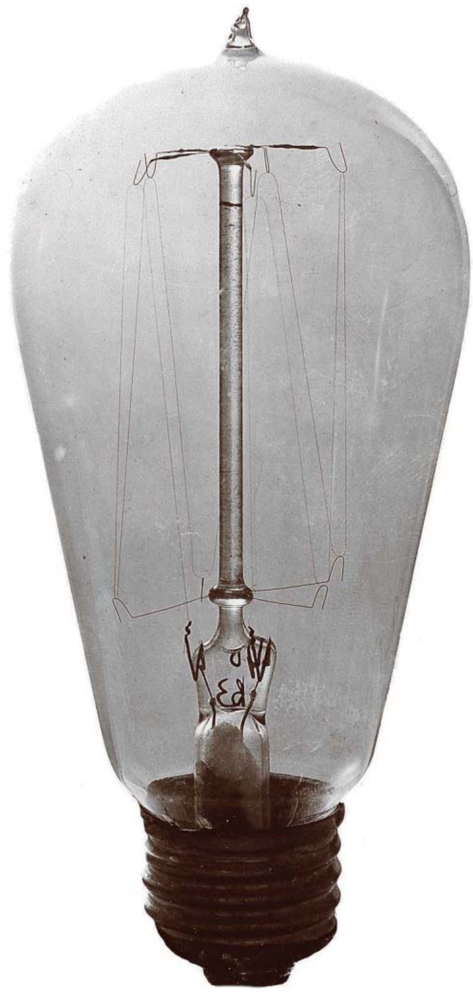
These people are among the last holdouts in a love affair with incandescent lighting that goes back a century and a half. For them, and for all of us who have spent years basking in incandescence, we offer a fond farewell to a brilliant notion.

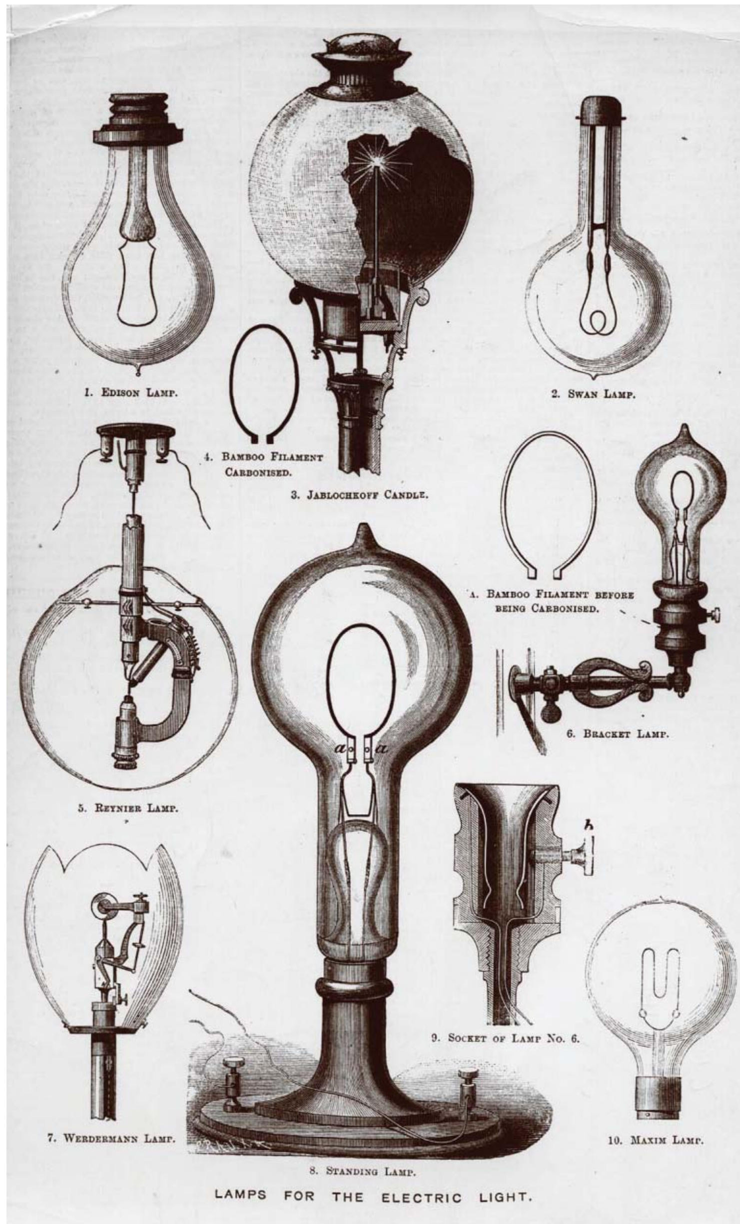
THE INCANDESCENT LAMP originated in experiments in the early years of the 19th century, when researchers heated thin wires by passing electric current through them. Their goal was to produce light by making a wire white hot, but it wasn't easy.

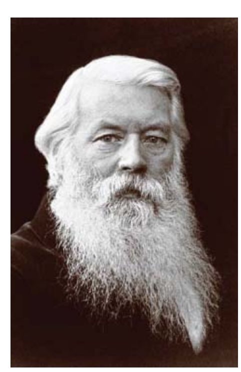
William Grove, a professor of chemistry at the Royal Institution in London, published his experiments in *Philosophical Magazine* in 1844. He reported that he had heated "a coil of platinum wire as near to the point of fusion as was practicable" and that it gave enough light to read by. He used the rare and expensive metal platinum because it was the only material that could be made white hot in air without melting or bursting into flame.

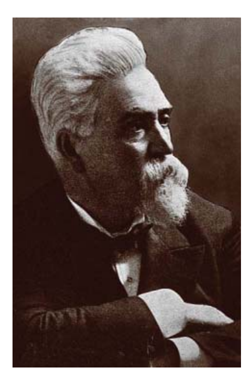
Happily enough, the material eventually adopted for the filament, as we now call it, was carbon, not platinum. Put carbon in a vacuum and you can heat it to a higher temperature than any metal without burning. But creating that vacuum was problematic. Finally, around 1870, Hermann Sprengel, a German chemist working in London, developed his vacuum pump. Sprengel connected a vessel to a narrow vertical tube; drops of mercury falling down the tube sucked air out of the vessel, pushing it down to the bottom of the tube where it escaped.

With an effective vacuum pump available, several inventors soon produced working lamps. In August 1881, four of them—Thomas Edison and Hiram Maxim from the United States and Joseph Swan and St. George Lane Fox-Pitt from England—displayed their bulbs in Paris at the International









INVENTING INCANDESCENCE: William Grove [above, left], Joseph Swan [center], and Hiram Maxim, along with Edison, all contributed to the evolution of incandescent light. Early ideas for incandescent bulbs abounded [top right], but by 1911, bulbs, like this General Electric tungsten lamp [top left], started looking a lot like they do today. Gas lighting, competing with electric light, didn't go quietly into the dark night without its own innovations: Austrian inventor Carl Auer von Welsbach created this gas mantle design in the 1890s [left].

CLOCKWISE FROM TOP LEFT: SCHENECTADY MUSEUM/SUITS-BUECHE PLANETARIUM; HULTON ARCHIVE/GETTY IMAGES; POPPERFOTO/GETTY IMAGES; SSPL/GETTY IMAGES (3)

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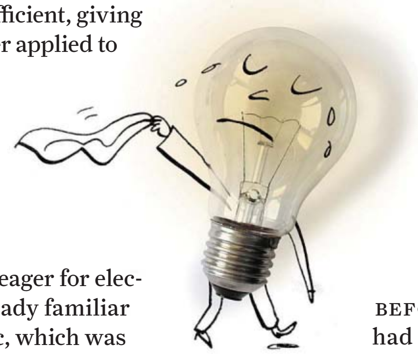
LOVELY LIGHT: Consumers embraced the tungsten bulb, and manufacturers eagerly indulged this passion through the decades. The London Electricity board in 1960 installed a lightbulb vending machine in its showroom [left]; in the 1940s [right], manufacturers published instructions with photographs for taking care of electric appliances, including incandescent lamps.

PHOTOS: LEFT: KEYSTONE/GETTY IMAGES; RIGHT: NINA LEEN/TIME LIFE PICTURES/GETTY IMAGES

Exposition of Electricity, which was attended by almost a million people. The lamps differed mainly in the choice of the material that was charred in a furnace to create the carbon filament. Edison began with bamboo fiber, Swan with cotton, Maxim with paper, and Fox-Pitt with grass. The Exposition Jury measured the efficiency of the various lamps, expressing that efficiency as candlepower—the light generated by a typical wax candle—per horsepower required to produce it. Edison's lamps ranked as the most efficient, giving 196 candlepower of light per horsepower applied to the generator. Maxim's gave 151, and the other two scored in between. The jury didn't consider how long each lamp lasted, and at that time it wasn't generally appreciated that the life of a filament lamp and its efficiency are interchangeable.

By this time the general public was eager for electric light in the home. People were already familiar with the brilliant light of the electric arc, which was created by passing a current between two electrodes. The arc lit up very large buildings and streets but was far too bright for home use. Filament lamps were more suitable; they were smaller and lit a room comfortably.

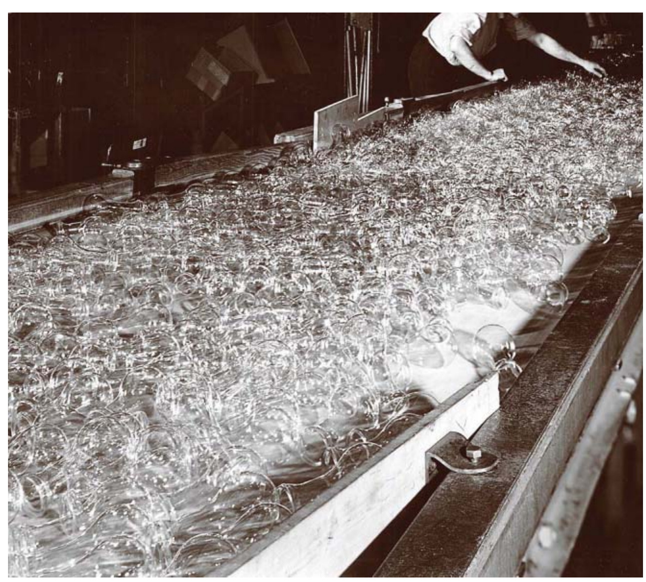
But all electric lights need an electricity supply, and this was not readily available at first. Cities that were planning street lighting, along with a few wealthy people planning to light their homes, installed their own generating plants. But ordinary middle-class folks had to wait for a public supply with electricity generated in a central station and distributed by wires to customers. Public power wasn't available anywhere until the early 1880s, but from then on, the demand for electric lighting in homes drove very rapid growth of the power industry in the United States, the United Kingdom, and most of Europe.



SERGE BLOCH

The first public supply was set up in Godalming, in southern England, in late 1881. It was built by two men named Calder and Barrett, about whom very little is known—not even their first names. A generator built by Edison began operating in London early in 1882, and another at Pearl Street, New York City, later that year. Several companies and some local governments then established generating stations on both sides of the Atlantic.

BEFORE IT COULD FLOURISH, electric lighting had to defeat an entrenched competitor in many towns—gas. In the mid- and late 19th century, gaslight simply meant a bare gas flame, so the electric lamp, which produced no smoke, was a clear winner. But the gas industry didn't give up easily; it developed the gas mantle during the 1880s, then greatly improved it in the 1890s. This fine mesh, made mainly of thorium oxide, became incandescent when heated by a gas flame smaller than what had been used in previous generations of gas lamps. This technology also allowed the industry to change



MANUFACTURING MAGIC: Glass bulbs flow along an assembly line at General Electric's Pitney Glass Works in Cleveland, in the 1950s [above right]; workers attach bases to the glass bulbs, in the early 1900s [left]. At the end of the process, the bulbs were tested, as shown in this photo taken at GE's NELA Park facility, also in Cleveland, in the 1930s [top]. *PHOTOS: SCHENECTADY MUSEUM/SUITS-BUECHE PLANETARIUM (3)* the composition of its gas so that the flames produced more heat and less light—and less smoke. The gas mantle turned out to be a cheaper source of light than the carbon filament lamp. Score round one to gas.

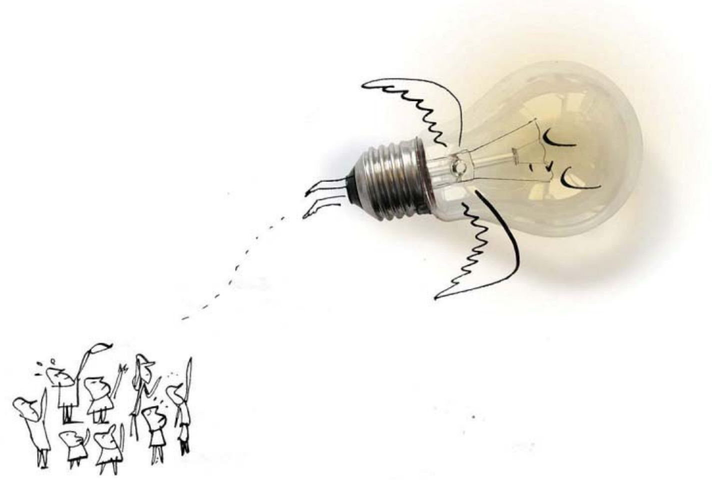
Starting around 1899, electricity answered the gas mantle with the metal filament, which could be operated at a hotter temperature, and therefore more efficiently, than a carbon filament. Developers tried several different filament materials. Osmium, tantalum, and tungsten have the highest melting points in the metals family but differ in their malleability. Initially, lamp manufacturers used osmium, also seen in the tips of fountain pens and in some heavy-duty electrical contacts, and tantalum, which was first isolated in 1902. Tungsten was attractive because it has the highest melting point of all metals—just over 3400 °C. But its brittleness stymied developers who were trying to draw it into a thin wire. Then Alexander Just and Franz Hanaman, working in Vienna and Budapest, found that they could make tungsten filaments by mixing tungsten powder with a binder and then drawing that mixture into a wire and sintering it—that is, heating it until the particles adhere but do not melt. Hugo Hirst, of the (British) General Electric Co., working with Just and Hanaman, began producing tungsten lamps in 1909, in a factory in West London. William Coolidge, of the (U.S.) General Electric Co., found that if he compressed tungsten powder and hammered it, he could draw it into a wire without using any binder, which was a simpler process. (There was no connection between the two General Electric companies.) Thus was born, in 1911, the drawn-tungsten filament incandescent lamp. It continues to be the standard in incandescent bulbs to this day, 100 years later.

In early tungsten lamps, the filaments sat in near vacuums, but it turned out that a little nitrogen or argon reduced the evaporation of the metal and prolonged the filament's life. The problem was that the gas also cooled the filament, making the lamp less efficient. Winding the filament in a coil reduced the cooling, and winding the coil itself into a coil, a technique developed in the early 1930s, worked even better. And that coiled-coil filament design has never been superseded.

In 1959, General Electric (U.S.) refined the filament lamp one more time. Its researchers sealed a tungsten filament into a compact bulb containing an inert gas and a small amount of a halogen, usually iodine or bromine. (The halogens are a group of elements that react very readily and energetically with other substances.)

In a halogen bulb, the halogen gas combines with the minute particles of tungsten that evaporate from the filament, which in ordinary incandescent lamps are deposited mostly on the inner surface of the bulb and over time gradually dim the light output. The tungsten halide that forms moves around as a gas and then, when it nears the hot filament, breaks down, redepositing the tungsten back onto the filament and releasing the halogen to repeat the process.

This halogen cycle keeps the bulb clean and the light output almost constant over the life of the bulb. The bulb temperature must be higher than in conventional incandescent lamps, too high for glass at the time, so the bulb was initially made of quartz. Because the first halogen lamps used iodine as the halogen, they were known as "quartz iodine" lamps. Later, bromine replaced iodine, higher-



melting-point glass replaced the expensive quartz, and the lamps became "tungsten halogen" lamps. The bulbs soon caught on for spotlights and projectors and eventually for general lighting. Right now, because they are somewhat more efficient than the standard incandescent lamp, they are not on the chopping block in any country.

ALTERNATIVES TO the ordinary tungsten incandescent bulb have long been available but found few takers for residential use until recently. People like the warm and brilliant glow of a tungsten incandescent, which in any case seems inexpensive compared with the other options. Of course, the familiar bulb is cheap only initially; in the long run, its inefficiency means a much higher operating cost and also more harm to the environment than the alternatives.

Commercial and industrial buildings have relied on fluorescent lamps since the 1940s. Discharging electricity in a long glass tube filled with a mixture of argon and mercury vapor produces ultraviolet light; a fluorescent coating on the inside of the tube turns the UV rays into visible light. Decades later, research into fluorescent materials and developments in control circuitry led to the compact fluorescent lamp. Launched by Philips simultaneously in Europe and the United States in 1980, these lamps fit into standard incandescent fixtures and used only a quarter of the electricity for a given amount of light.

Nevertheless, the heir apparent to the incandescent lightbulb isn't the compact fluorescent but rather the LED, which seems poised to dominate home lighting in the next decade. This semiconductor device came into commercial use in the 1960s, but the dim red or yellow LEDs available in those days weren't good for much besides indicating whether an electronic gizmo was on or off. Today, however, advanced and high-power LEDs throw off a brighter white light more efficiently than any other source. But their initial cost is higher, and the colors available don't map exactly with the familiar incandescent glow. Other alternatives, all experimental at this stage, are also in the offing. Ironically, one of them is an attempt to adapt for home lighting the technology that is now largely obsolete in television sets: the cathode ray tube—an electron beam hitting a phosphor.

Technology marches on, as it is wont to do. Soon, it will leave behind one of its most storied and successful creations. We'll miss the incandescent lamp, while wishing its successors an equally brilliant tenure. ❑

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Cognitive-Radio Games

Continued from page 41

million bytes more or a few million less. Channel conditions for player C could sometimes become so poor that the pair would not be able to exchange any bytes at all.

It would, of course, be silly to allocate a second of precious airtime to player C during such moments. Better to give that particular 1-second slot to another player that can use it. You can allocate an extra time slot to player C when its channel conditions improve.

That makes for only a minor variation on a simple round-robin. You still split up the periods of exclusive spectrum use into three equal parts and divide them equally among the three players. But you arrange the three-way division of time slots more intelligently, giving each player the slots that are most beneficial to it.

Many cellular base stations do exactly this. It's easy to accomplish, because the base station, being a participant in each exchange, knows what the channel conditions are for everyone. To do something like that when there is no central controller, you'd have to set aside a sliver of the spectrum at hand so that the different players could exchange such information. Each player would send the others second-by-second reports of its channel conditions and would follow a rule saying that the one who can best take advantage of a given time slot could use it. "Best advantage" would be measured by comparing how quickly each player could transfer information with how quickly that player communicated on average in the recent past.

Let me try to make this strategy more concrete. If, say, player C could communicate at 2 million B/s during a particular time slot—twice C's average rate—C would receive a rating of 2. If B could send only 2.5 million bytes in that same time slot instead of its usual 5 million, B would receive a rating of 0.5. If A could send 15 million bytes instead of its normal 10 million, A would get a rating of 1.5. Because C earned the highest rating, C would get to use that time slot.

One second later, the players again would gauge what the ensuing 1-second time slot promised to provide them and then compare those values with their average throughputs. And once again, the player with the highest rating would enjoy exclusive use of the airwaves for the following second.

You're now primed to ask the obvious question: Why would these players share their private information about how good their radio channels are? Wouldn't players be tempted to exaggerate the quality of their channels so that their ratings would be high enough to win the use of the upcoming time slot? It would seem that such a system is just another example of the classic prisoner's dilemma, dooming this scheme to failure.

Maybe not. With a simple modification to this arrangement, the players could, in fact, be coaxed to cooperate, resulting in a proportionally fair allotment of the available radio spectrum.

One way to do that for these three players goes like this: To start, the players have to keep scorecards. If one of them is cheating, that player will end up with more than a fair one-third share of the time slots. In short order, the other players will recognize this and realize that the cheating player is exaggerating its channel quality. The other players can then punish the offending player by refusing to play nice for some set period of time.

During the subsequent punishment phase, a Hobbesian electromagnetic war rages. The airwaves rapidly become so cluttered with competing transmissions that nobody is able to get through. Perhaps it's not as nasty as all that, but things are still bad enough that everybody's transmission rate plummets.

We have worked out the mathematical details of this scheme—how you detect cheating and how long the system must continue to remain in the punishment phase to wipe out any ill-gotten gain a cheating player may garner in the short term. If the players' cognitive radios follow our prescriptions, nobody will ever have an incentive to cheat.

The basic concept we used to arrive at that happy conclusion is easy enough to understand. We just had to model a repeated game, where players make decisions about how to act based on the other players' past moves. Cooperation then emerges from the threat of punishment, as I described, or by developing mechanisms to track and reward individual reputation, by fostering mutual trust, and so on.

I've been studying various ways to do that using something called mechanism design theory, a component of modern game theory forged by Leonid Hurwicz, Eric S. Maskin, and Roger B. Myerson, who together won the Nobel Prize in Economics for this work in 2007. They showed that by carefully setting up the game and its rules, the system's designer can give even the most self-interested players incentives to behave.

The cognitive-radio game I've sketched here is admittedly an idealization. Things rapidly become more complicated when you consider more realistic spectrum-sharing situations. For some frequency bands, for example, a primary licensee will be involved, in which case you need to figure in the value of the payments secondary users must make to the "owner" of the spectrum (or even to one another) in determining their motivations. Also, real cognitive radios are able to adjust in more ways than just by switching their transmissions on or off. They can be required to limit the amount of power they use to transmit or to shift to a protocol that sends less data but produces less interference for others. The variations are nearly endless.

Yet another complication I've glossed over is how to ensure that the system doesn't fall prey to what's known as a Sybil attack, where one player pretends to be multiple players, harvesting the privileges allotted to each. Worse, it may have to deal with participants whose only aim is to disrupt communications.

Although I and other engineers have been fruitfully applying classical game theory to wireless communications, this branch of mathematics hasn't by any means provided universal solutions to all possible problems. But it does offer a framework for analyzing challenges and constructing defenses.

Game theory's first blossoming took place more than a half-century ago, under the dark military and economic clouds of that era. The world today is a very different place. But there is no shortage of competitive, cooperative, and conflicting interactions of selfish or malicious players to contend with—ones that nowadays are often governed by algorithms rather than by psychology. For making those parts of life work more smoothly, nothing is better suited than game theory. ❏

TO PROBE FURTHER See K.J.R. Liu and B. Wang, Cognitive Radio Networking and Security: A Game-Theoretic View, *Cambridge University Press, 2010.*

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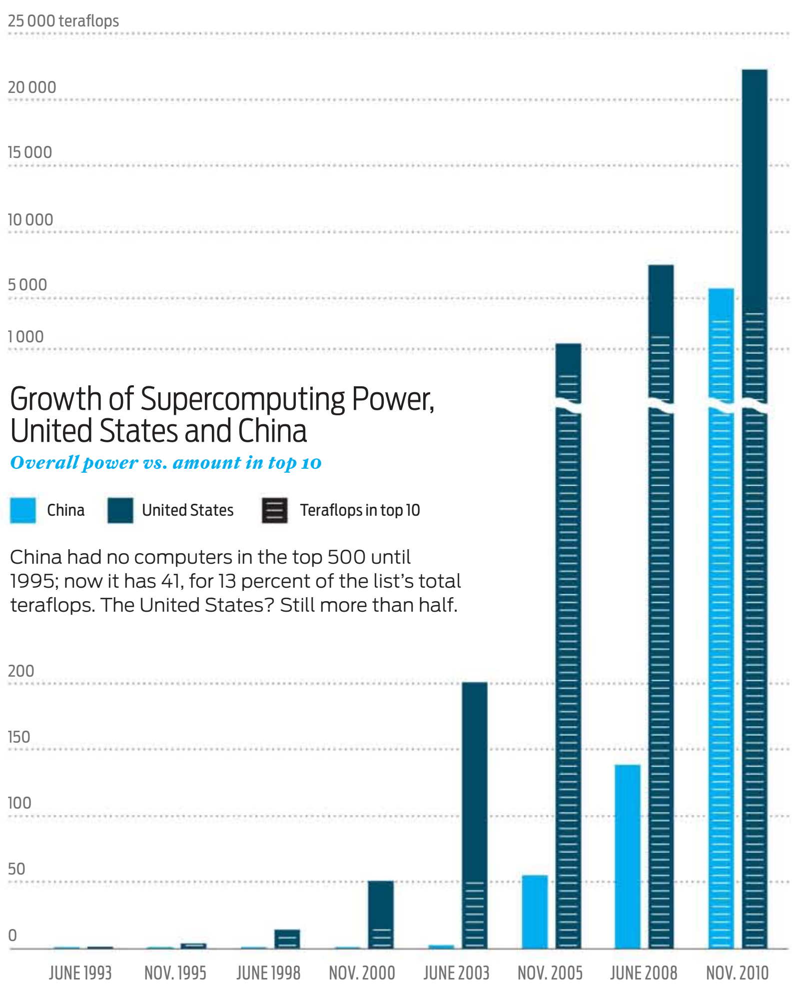

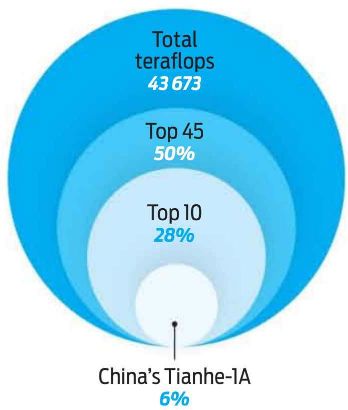

The United States and China have most of the teraflops, and most of theirs are generated by a handful of top machines.

Source: Top500.org

China's Supercomputing Prowess

DID YOU feel that? That was the supercomputing world lurching eastward. In the last accounting of the world's 500 fastest machines, China surprised everyone by taking the top spot. It's gone from having 3 in the top 500 at the beginning of the decade to 41, besting historic processing princes Germany and Japan.

China is still far behind the consistent computational king, the United States, which has historically commanded about half the list. But world-class supercomputing prowess—or at least the bragging rights to it conferred by the Top 500 list—is more a question of quality than of quantity.

Add up the processing potential of all 500 top supercomputers and you get an almost unfathomable 43 673 000 billion floating-point operations per second (43 673 teraflops). But it's the cream of the crop that make all the difference. By themselves, the top 10 computers provide 28 percent of the list's teraflops, and you need only the top 45 machines to account for half. China's big break came not by doubling its presence on the list but by building one really powerful computer at its apex. The Tianhe-1A system at the National Supercomputer Center, in Tianjin, boasts a performance of 2570 teraflops—about 6 percent of the list's total.

Another reckoning of the supercomputer universe is due in June. Watch for new high-ranking entrants from Japan, the United States—and China. —*Samuel K. Moore*

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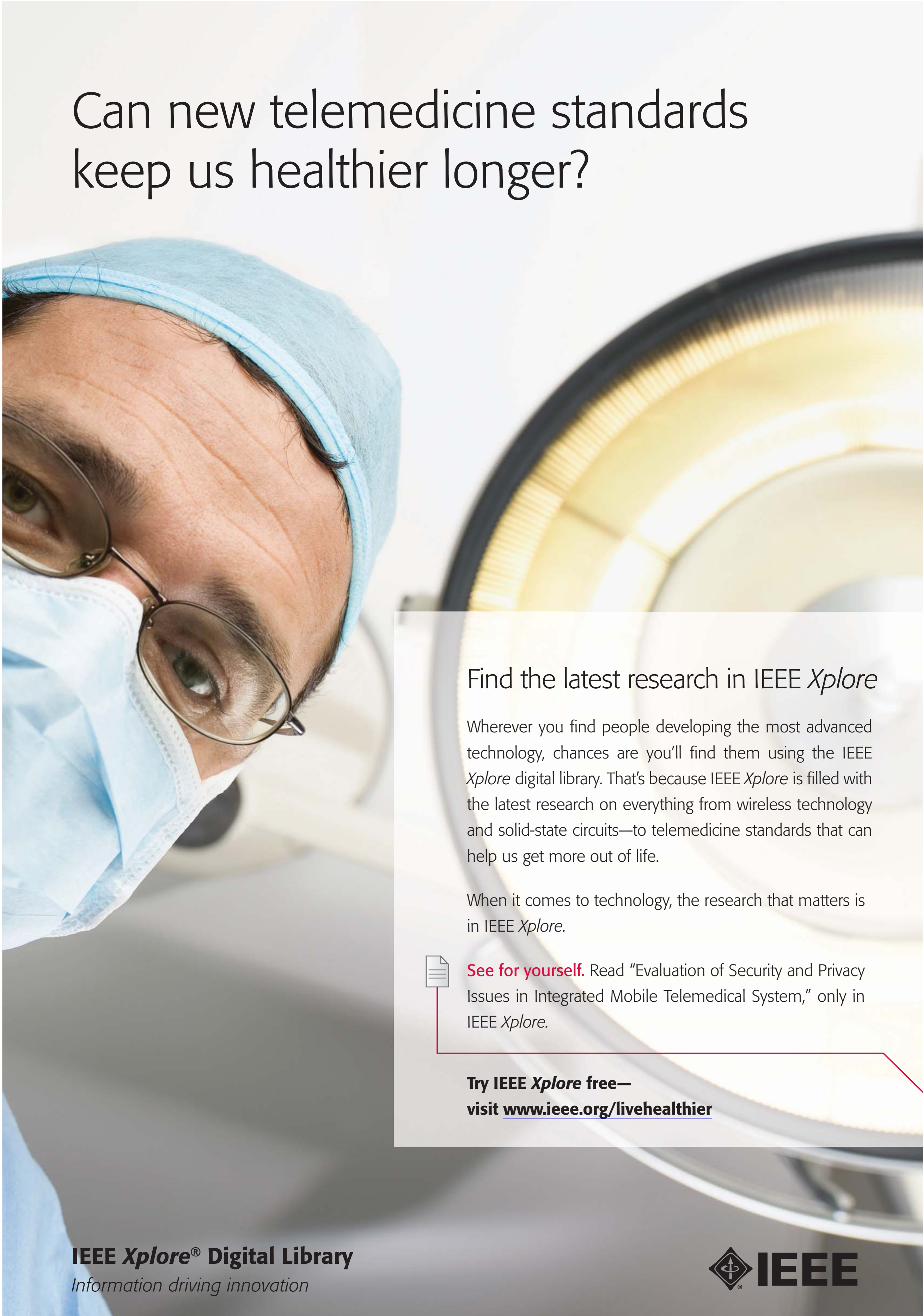

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