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THE MAGAZINE OF TECHNOLOGY INSIDERS
03.09

Disappearing Deterrent

THOUSANDS OF NUCLEAR WEAPONS WILL SOON BE TOO OLD TO COUNT ON. HERE'S WHY FIXING THEM MAKES MORE SENSE THAN REPLACING THEM

BRINGING PROSTHETIC ARMS INTO THE 21ST CENTURY

YOUR PLUG-IN CAR: NOT SO GREEN AFTER ALL

THE LASER KITTY TEASER AND OTHER PATENT NONSENSE

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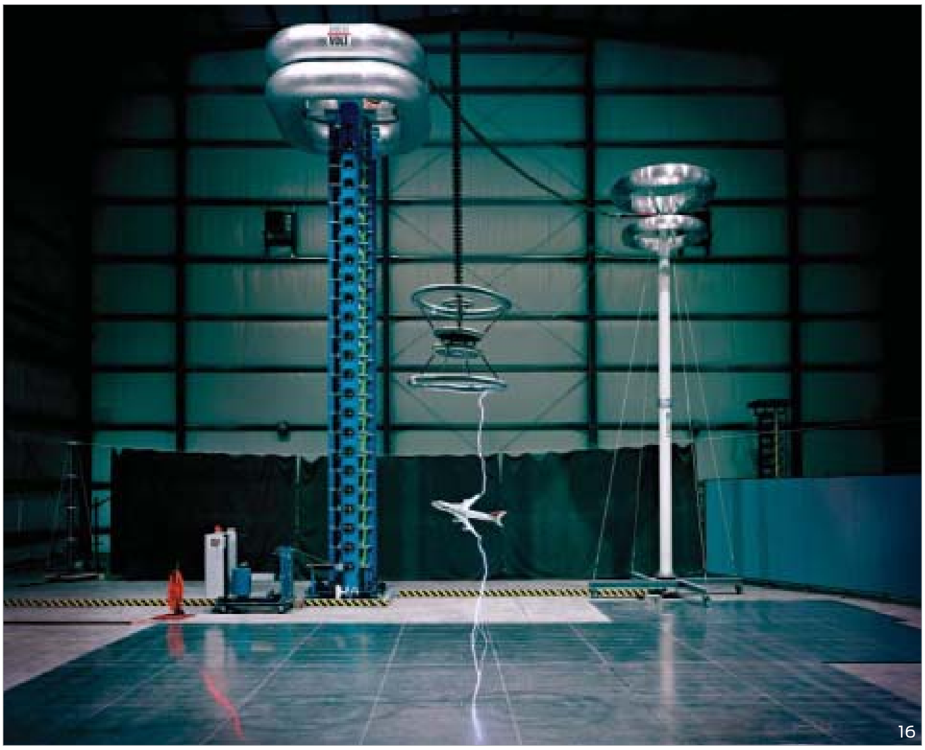

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A LITTLE TURBULENCE: By zapping model aircraft, Lightning Technologies is helping engineers protect electronic systems on real aircraft from storms.

COVER: BRYAN CHRISTIE DESIGN

THIS PAGE: BOB O'CONNOR

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LEFT: KIM SHIFLETT/ NASA; RIGHT: MATTHEW NAGER

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SEEKING "TREASURES HIDDEN IN THE HEAVENS"

The quest to answer the age-old question of whether there are other planets like ours will continue this month. NASA's *Kepler* spacecraft [above] is scheduled to launch on 5 March from Cape Canaveral. The new planet hunter, which can observe 100 000 stars simultaneously, will explore the structure and diversity of planetary systems and seek Earth-like planets in or near the habitable zone—the distance from a star where liquid water can exist on a planet's surface.

ONLINE FEATURES:

PROGRAMMING FOR THE CLOUD: Game developers are excited about the possibilities of off-loading graphics rendering to a supercomputer.

THE THREE-WAY BATTLE: Texas Instruments, 3M, and Microvision are all vying to put a pico projector in the palm of your hand.

DREAM ON: Listen every Thursday in March for a new Dream Jobs profile podcast.

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IEEE MEDAL OF HONOR GOES TO DRAM DEVELOPER

IEEE Life Fellow Robert H. Dennard is this year's recipient of the IEEE Medal of Honor, for his invention of single-transistor dynamic random-access memory and for developing scaling principles for integrated circuits. DRAM has become the standard for RAM and is used in most computers today.

BUZZ PATROL

IEEE Member Alan Eynon is a mild-mannered signal-processing engineer, but his beekeeping hobby keeps people abuzz.

PUBLIC VISIBILITY PICKS UP STEAM

Ten months into IEEE's Public Visibility Initiative, the program has attracted news coverage in 10 countries and unveiled a revamped newsroom. Plus, more and more members are signing up to be IEEE technical experts.

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back story

Geek Summer

COURTESY OF STEVEN FRANK

ON A HUMID Saturday afternoon in late June of 1978, a dark blue gas guzzler glides up to a dormitory at Rensselaer Polytechnic Institute (RPI) in Troy, N.Y. It deposits Steve, a bright high school junior from Fair Lawn, N.J., and a big trunk stuffed with jeans and rock-concert T-shirts. He looks around at the odd mix of industrial architecture, abandoned factory buildings, and manicured lawns and wonders what people do for fun in such a place.

Along with 150 other high school students, Steve will be taking courses and getting a taste of what college is like. His concern, amid this congregation of elite teenage scientific precocity, is that he may not manage to find someone whose idea of fun doesn't necessarily involve an HP programmable calculator.

Those fears are allayed a few days later, when he meets Glenn, from Stratford, Conn. They have been sent to RPI for much the same reasons other kids are sent to military academies—so that they may learn esoteric but possibly useful things in a structured environment, away from bad influences, where they will undoubtedly be too busy to get into trouble.

Over the next three months the two are inseparable. They play racquetball and swim. They listen to countless radio broadcasts of Gerry Rafferty's "Baker Street" and the Cars' "Just What I Needed." They fly 45-rpm records off the roof of RPI's Jonsson Engineering Center. They learn how to program the IBM System/370 mainframe computer in FORTRAN 77, using punch cards.

They find parallels between William Golding's *Lord of the Flies* and Joseph Conrad's *Heart of Darkness*. They have adventures and misadventures involving beer, Schedule I controlled substances, and illegal fireworks, including an episode involving all three that nearly gets them kicked out of the program and their RPI credits revoked. (So much for the "too busy to get into trouble" theory.)

A year later, Steve goes off to Princeton to major in chemistry and Glenn to Brown for electrical engineering. They keep up a steady stream of letters and occasional visits, during one of which, in Providence, R.I., in 1980, Steve decides to transfer to Brown, from which they both graduate in 1983 [see photo].

After college, Glenn goes on to work in science and technology journalism, winding up twice at *IEEE Spectrum*. He still works there today. Steve goes to Harvard Law School, staying on in Boston to work as a patent attorney by day and a writer by night. His first novel, *The Uncertainty Principle*, published in 1997, contains several scenes that uncannily resemble actual events at RPI in the summer of 1978. His most recent magazine article, "The Death of Business-Method Patents," appears in this issue. ❑

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 Update page is in *IEEE Spectrum*, Vol. 46, no. 3 (INT), March 2009, p. 9, or in *IEEE Spectrum*, Vol. 46, no. 3 (NA), March 2009, p. 11.

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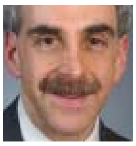
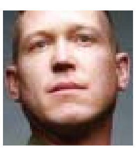
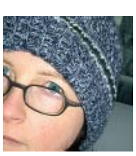
contributors



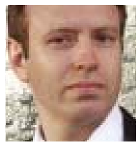
STEVEN J. FRANK, a graduate of Harvard Law School and an intellectual-property attorney in Boston, wrote "The Death of Business-Method Patents" [p. 32]. His turn-ons are Italian Barolo wines, bicycle touring, and Mediterranean travel. Turn-offs include mean people, air pollution, and cruelty to animals. Frank's latest book is *Intellectual Property for Investors and Technology Managers* (Cambridge University Press, 2006).



JONATHAN KUNIHOLM is a veteran of the Iraq war, an engineering researcher at Duke University, and an amputee. You might remember him from the cover photo of our January Winners & Losers issue, in which he wears a prototype of the (winning) Revolutionizing Prosthetics arm. In "Open Arms" [p. 36], he talks about what it will take to keep prosthetics technology advancing long after the government funding has stopped.

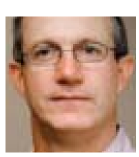


HOLLY LINDEM, based in Texas, created photo-illustrations for two features in this issue. For "Open Arms" [p. 36], "I decided to blend maps with the building blocks in the arm to show the global nature of the project," she says. "Maps are beautiful, and the roads are reminiscent of veins." The car-shaped metal grid she built for "How Green Is My Plug-In?" [p. 42] "took many hours of measuring, cutting, and filing," she says. "Adding the outlets and the color green helped provide an immediate read." As a finishing touch, Lindem glued on bits of rust from a cache of the stuff she keeps in her studio.



ROBB MANDELBAUM, originally from Iowa, has a thing for trains. Naturally, he had to experience railroad braking for himself, so for "Stop That Train" [p. 46] he left his Brooklyn, N.Y., home for Appalachia and caught a ride with the Norfolk Southern Railway. The route is one of the first where electronically controlled braking has since been deployed. "You'd think 6 hours in a locomotive cab would wear thin after a while," he says. "But I loved every minute of it."

FRANCIS SLAKEY and **BENN TANNENBAUM,** authors of "What About the Nukes?" [p. 24], are Ph.D. physicists who now work on science and technology policy in Washington, D.C. Slakey is the Upjohn Professor of Science and Public Policy at Georgetown University and associate director of public affairs for the American Physical Society. Tannenbaum is the associate program director of the Center for Science, Technology and Security Policy at the American Association for the Advancement of Science.



JOHN VOELCKER didn't expect to delve into energy policy when he became *IEEE Spectrum*'s automotive editor, but it may have been inevitable. The push for electric vehicles addresses global warming and energy security, so designing future cars requires more knowledge of the energy sector than before. For Voelcker, the best part of writing "How Green Is My Plug-In?" [p. 42] was learning that he was asking questions at the same time researchers were. "That made me confident that my coverage was headed in the right direction," he says.

CLOCKWISE FROM TOP LEFT: GOODWIN PROCTER, RANDI SILBERMAN (2), HOLLY LINDEM, MIKE McGREGOR

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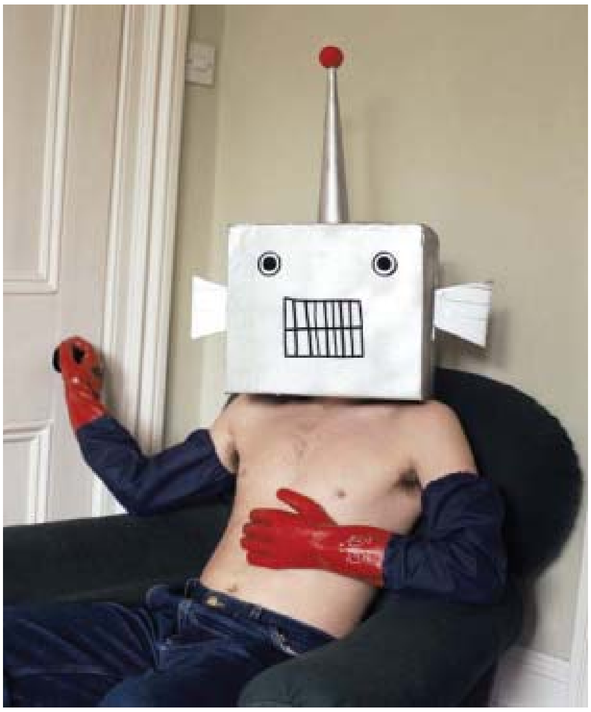
spectral lines

California Dreamin'

While archrival Microsoft hemorrhages cash and employees, Google is mapping out its plan for benevolent world domination. The company is flush, with US $16 billion in cash at press time, and its investment in new and existing projects constitutes a miniature economic-stimulus package unto itself. In November it was the Google Android cellphone. Last month it was the new interactive maps Google Earth Ocean and Google Mars, as well as Google Latitude, which allows subscribers to locate each other anytime, anywhere. And then there's the new Chrome Web browser. Clearly, Google's investment in R&D—$2.1 billion in 2007, according to *IEEE Spectrum*'s latest R&D 100 survey (http://www.spectrum.ieee.org/rndcalc)—is bearing some luscious, and potentially lucrative, fruit.

But not every idea coming out of Google is a home run. Sometimes it's a punch line to a joke waiting to happen. Witness the company's recent investment in Ray Kurzweil's Singularity University. The amount of money is insignificant by Google's standards—at a minimum of $250 000 (the Corporate Founder level), it's less than a thousandth of one percent of cash on hand. The effect on the company's good name might prove to be less trivial.

Still, you've gotta admire the sheer chutzpah of it. In the middle of the worst economic crisis in a lifetime came word that Google and NASA are bankrolling the "university" at NASA's Ames Research Center, not far from Google's headquarters in Mountain View, Calif. "We are anchoring the university in what is the lab today, with an understanding of what's in the realm of possibility in the future," Peter Diamandis, vice-chancellor of Kurzweil's Klown Kollege and chairman and CEO of the X Prize Foundation, told the *Financial Times*. "The day before something is truly a breakthrough, it's a crazy idea."



ANNIE COLLINGE/GETTY IMAGES

We're right with you, Peter, at least the crazy part, as much of the coverage in *Spectrum*'s special report on the singularity makes clear [see http://www.spectrum.ieee.org/singularity]. As Diamandis says, anything is in the realm of possibility in the future. The sun might explode tomorrow. Osama bin Laden might start doing stand-up comedy routines in Las Vegas. And Ray Kurzweil might help usher in a beneficent singularity, where machines smarter than we can imagine treat us, as science-fiction writer and singularity theorist Vernor Vinge once said, like pets.

Hey, why not? We're already throwing billions, if not trillions, of dollars at an economic mess in part facilitated by financial-risk algorithms, the crazy uncles of our future machine overlords. Leaving aside NASA's questionable role in this whole enterprise, Google is free to blow money on the kind of interdisciplinary research that, in Kurzweil's vision, will make him immortal. And with a faculty graced by some of Google's heavy hitters, like Peter Norvig and Vinton Cerf—as well as non-Googlers like medical doctor Terry Grossman, Kurzweil's coauthor on *Fantastic Voyage: Live Long Enough to Live Forever* and partner in expensive dietary supplements—no doubt a few eager postdocs will fork over $25 000 for nine weeks of study. Let's add a few more to the sad tally of good human minds sucked into the thrall of Mr. Kurzweil and his obsessive quest to deny Death his due. But while they're at it, we're wondering if Google might throw *Spectrum* some cash, too. One of our editors has volunteered to live long enough to live forever, and a few years' worth of Ray & Terry's Anti-Aging MultiPack ($86.75 per 30-day supply), plus the hefty cost of the consciousness upload, is going to stress our limited budget.

Or we could take that money and do something worthwhile. If you had $1 million to bestow on an educational institution, what would you want your money to fund? Tell us at http://www.spectrum.ieee.org/milliondollarideas.

—Harry Goldstein

Part of this column appeared in our Tech Talk blog on 3 February 2009.

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forum

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YOU WIN SOME, YOU LOSE SOME

WELL DONE on the latest Winners & Losers [January]. The bit on Emotiv Systems ["Mental Block," Loser, Interfaces] was spot-on. That is my area of research [see the clip of "James May's Big Ideas" at http://uk.youtube.com/watch?v=Uyrd0uOuyms], and all the evidence points to the fact that Emotiv's Epoc headset is not purely a brain-computer interface. In itself that is not a problem, if the headset works. However, the company's claim is misleading if the device is purely motor or muscle based! Emotiv's Web site has a video [http://emotiv.com/INDS_2/inds_2_1.html] showing a man using an Emotiv system to move a wheelchair. The occupant controls it by allegedly grinning (grimacing is more like it) and winking with his left eye or his right—all extracerebral and muscular inputs! I couldn't have written the article better myself.

CHRISTOPHER J. JAMES
IEEE Fellow
Southampton, England

AS VICE president at Zyvex Labs, I am familiar with Geoffrey Ling's Defense Advanced Research Projects Agency program for artificial arms ["The Revolution Will Be Prosthetized," Winner, Robotics/Neurointegration]. Zyvex was working on an ancillary program of peripheral nerve interfacing, but it did not get integrated. I am proud to have been involved even in that small way. Your article was an excellent overview. I wholeheartedly agree that this is a technology winner.

JOHN N. RANDALL
IEEE Member
Richardson, Texas

I'M AFRAID that journalists are making a quick judgment regarding Randell Mills, founder of BlackLight Power ["Hot or Not?" Loser, Power & Energy]. There are many examples in human history of journalists using poor judgment in putting world-class scientists into the same basket as "losers." On the other hand, there are many great scientists who may not be liked among journalists and readers but whose contributions to the world are far more fruitful than those of dozens of Nobel Prize laureates. If Mills said he did the experiments and that the device works, then let time be the judge. Don't put the guy in the Losers category, because he might be doing great things, and we just don't fully understand them right now. Even if the author is speculating, it is too early to state that the project is a loser. In science there is no such thing as "impossible." Everything is possible.

PREDRAG MILOVAC
IEEE Member
Fremont, Calif.

I WAS DISAPPOINTED by your neglect of fundamental safety procedures in your article on the Aquada ["That Sinking Feeling," Loser, Automotive]. Were James Bond to be drinking anything alcoholic—dry martini or beer—while piloting a water vehicle on Lake Michigan, he would be violating U.S. Coast Guard regulations and endangering not only himself and his bikini-clad waterskiing beauty but other boaters as well. And don't say he was in Canadian waters—all of Lake Michigan is U.S. territory.

MARC HURWITZ
IEEE Member
Baltimore

CONTROL OR BE CONTROLLED

AFTER I read the articles about the RepRap, the self-replicating machine [Hands On, January], and "Sound Waves for Brain Waves" [Update, January] within minutes of one another, the solution to self-assembly seemed obvious to me. If a focused ultrasound device were attached to the machine, it could control the host (read "human"), inducing him or her to assemble the replicated parts into the second RepRap—possibly against the host's free will.

All joking aside, however, this scenario does offer an interesting thought experiment in the ethics and moral hazards of artificial autonomy and reproduction.

JASON BILLING
IEEE Member
Lubbock, Texas

CORRECTIONS

In "Multicore Made Simple" [Winners & Losers, January], Andy Keane was misquoted as saying, "Nvidia has already sold hundreds of thousands of its CUDA-enabled GPGPUs." The number should have been more than 100 million.

The images accompanying "Europe Replaces Old Wind Farms" [Update, January] should have been labeled as photo-illustrations.

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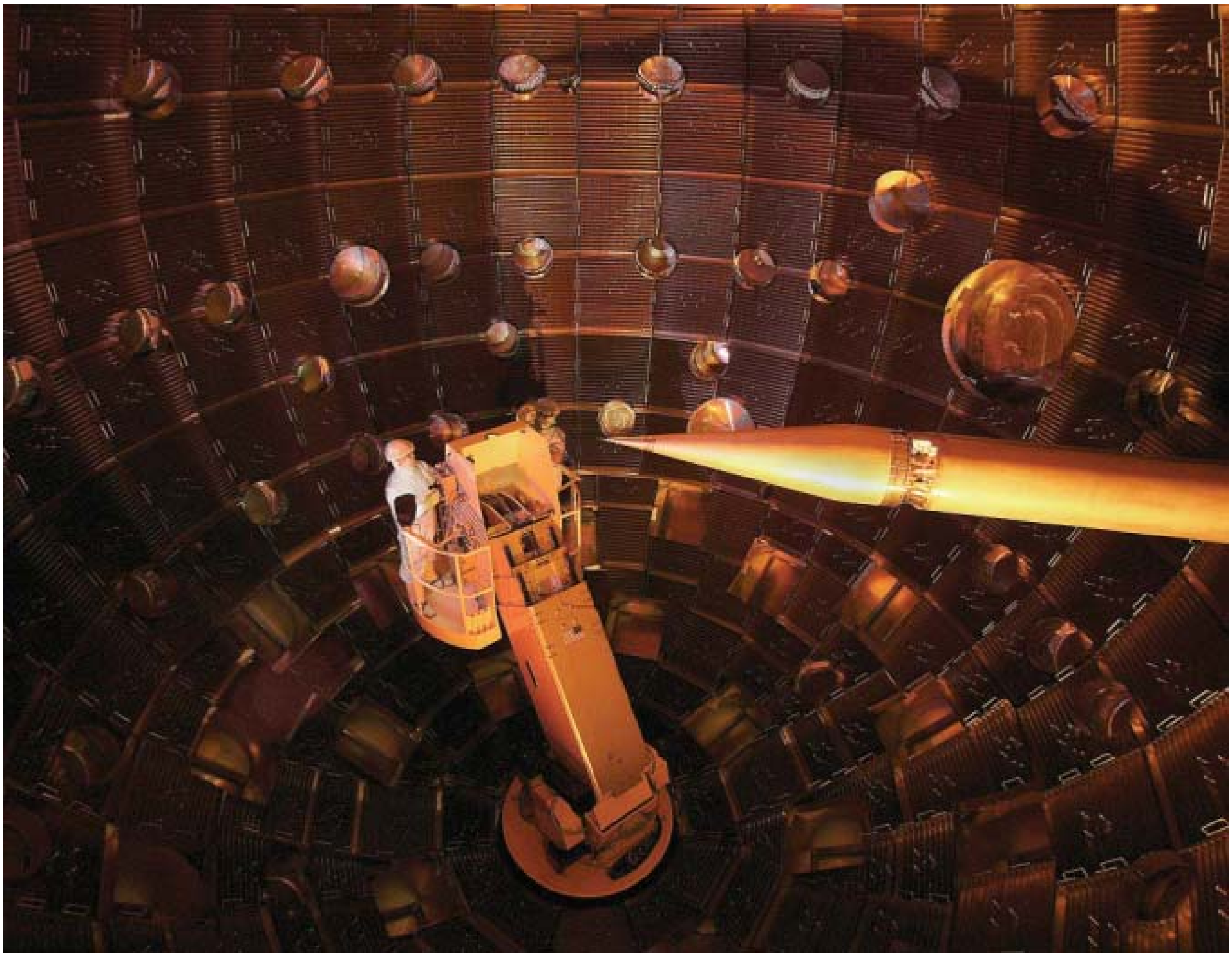

Fusion Factory Starts Up

The $4 billion U.S. National Ignition Facility opens for business

LATER THIS month in California, construction will be completed at Lawrence Livermore National Laboratory's National Ignition Facility, or NIF, the world's most powerful laser system—12 years and roughly US $3.5 billion after it was begun. The plan is for NIF's 192 neodymium lasers to create controlled moments of fusion by focusing their energy on 3-millimeter-wide pellets of deuterium and tritium. Together, the lasers will produce a 500-terawatt bolt of energy that will turn the surface of a target capsule to plasma. The plasma will then explode, compressing the hydrogen and creating shock waves that will squeeze the fusion fuel even further. The expected result is ignition, the start of a nuclear fire that will burn through the pellets, ultimately releasing up to 20 times as much energy as that introduced by the lasers.

When the project first got off the drawing board in 1996, the U.S. Department of Energy (DOE) had high hopes that NIF would strike three licks with the same stick. NIF's lasers, any one of which would alone be the world's most powerful, would help the DOE's National Nuclear Security Administration to safely maintain the United States' cache of nuclear weapons. Without any test detonation, NIF would validate supercomputer-generated three-

ON TARGET: The National Ignition Facility is nearing completion.
PHOTO: LAWRENCE LIVERMORE NATIONAL LABORATORY/DEPARTMENT OF ENERGY

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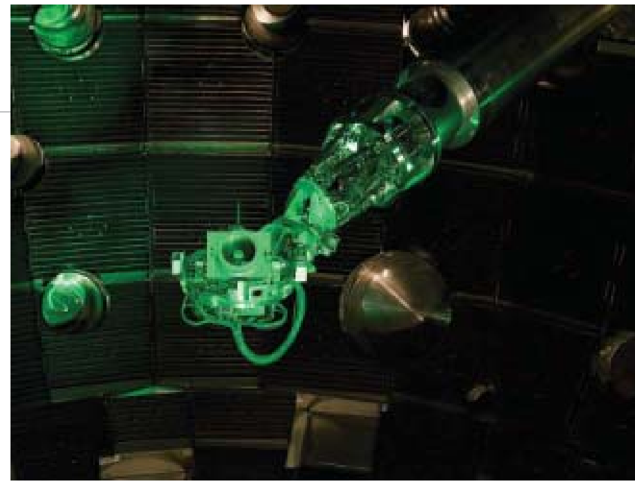
update

dimensional simulations of a thermonuclear burn. The project's champions also insisted that the 30-meter-tall behemoth would help scientists to better understand how to turn water into limitless amounts of carbon-free energy. And the project would advance basic astrophysics research, for example by simulating the explosion mechanisms inside supernovas.

The project, which broke ground in 1997, was supposed to be completed in 2002, at a cost of $1.07 billion. But technical problems triggered an avalanche of construction delays and cost overruns. So in 1999, the DOE swept the decks of NIF's management. The facility finally came in at about $3.5 billion and has met all its construction and spending targets since 2001, when its budget was adjusted to reflect what it would actually cost to complete.

By last December small-scale experiments had already begun, with researchers working two shifts a day, seven days a week, says Edward Moses, principal associate director in charge of NIF.

"We just did an experiment with the lasers running at 500 kilojoules," Moses says, though he won't discuss the specific aims of the work scientists were doing prior to the facility's official opening. "That's 20 times more than has ever been done before." Moses is confident that NIF will reach ignition when experiments aimed at achieving it begin in 2010. By 2012, he expects the Lawrence Livermore team to be able to start fusion reactions on demand and get 20 times as much energy as they put in.



INSPECTOR GADGET: An optics inspection system looks for trouble in the target chamber. PHOTO: LAWRENCE LIVERMORE NATIONAL LABORATORY/DEPARTMENT OF ENERGY

Will Washington Kick-start the U.S. Battery Biz?

The United States will need a domestic lithium-ion manufacturing industry to meet its plug-in goals

During his presidential campaign, Barack Obama promised to put 1 million plug-in hybrids and electric vehicles on U.S. roads by 2015, one of several steps toward energy independence. But getting there, say auto industry analysts, will require a heavy dose of government intervention and, crucially, the rapid construction of a domestic industry to manufacture advanced batteries. U.S. industry groups are pushing strongly for both.

Widespread penetration of plug-in cars remains far in the future. A Boston Consulting Group study predicts that under current trends, just 5 percent of new cars sold in the United States in 2020 (roughly 750 000 vehicles) will be plug-ins. Even 1 million plug-ins would still be less than one-half of 1 percent of the entire U.S. vehicle fleet of 250 million, but they would be more than 1000 times as much as the number on U.S. roads today.

The biggest impediment to Obama's goal is an insufficient supply of lithium cells, whose high energy density will enable viable plug-in vehicles, says Brian Wynne, president of the Washington, D.C.–based Electric Drive Transportation Association. Global capacity is tight for all automotive electric-drive components—motors, controllers, inverters—but especially so for large lithium-ion cells.

Automakers prefer nearby suppliers, to reduce risk and cut shipping costs. But while General Motors will build battery packs for its plug-in Chevrolet Volt in Michigan, the cells inside them will come all the way from South Korea, because lithium-ion cells aren't manufactured in volume anywhere in the United States. "It's important to be able to manufacture cells here, to control our own destiny," says Wynne. If electric drive takes off in other regions, he says, U.S. carmakers could be frozen out of limited supplies.

To build enough plants to supply cells for 1 million Volt-style plug-ins a year—16 plants at, say, US $300 million each—might cost $5 billion. But first, cell makers need "a big customer contract," says Mary Ann Wright, CEO of lithium battery supplier Johnson Controls-Saft. Beyond that, "we need a sane and rational energy policy" to stabilize gas prices, giving predictability to an industry that now makes billion-dollar bets years before cars go on sale. Such an energy policy, she says, would include low-interest loans to viable manufacturers, outright grants to jump-start the industry, and aggressive conversion of government fleets to electric drive, to stimulate demand.

As it happens, Johnson Controls-Saft owns the closest plant to the United States that produces automotive-grade lithium cells; it's in Nersac, France.

$4.6 BILLION The value of intellectual property lost to data theft by 800 companies in 2008, according to a survey by McAfee, a security-technology company in Santa Clara, Calif.

But some scientists both inside and outside the DOE grumble that NIF will make only a marginal contribution to the understanding of how best to maintain the United States' existing nuclear weapons stockpile [see "What About the Nukes?" in this issue]. "There is some science you can learn from NIF, but after you're done and you've spent upwards of $4 billion, the question you have to ask is whether it's worthwhile," says Ivan Oelrich, vice president for strategic security at the Federation of American Scientists, which issued a report in 2007 critical of NIF and two other big National Nuclear Security Administration's Stockpile Stewardship Program projects. The report asserts that NIF's funding would have been better spent on smaller, targeted research projects at the national laboratories or at dozens of universities.

"This is a case of better never than late," says one DOE nuclear weapons scientist, who spoke on the condition of anonymity. "We were told that we couldn't live without NIF because 'How else are we going to make sure that we know how the material inside the warheads will degrade?' Does this mean that the nuclear stockpile, more than a decade later and with NIF still not operational, is inherently unsafe?" he asks. "If not, then what do we need [NIF] for?"

Moses is dismissive of the Federation of American Scientists report. "Ever since I was brought in to manage this project, it has been under intense scientific and policy review and oversight from Congress," he says. "In every case, its validity has been reaffirmed and it has been re-funded."

Moses says he is confident that fusion-based electricity generation will be achieved within the next 10 to 15 years, but not at NIF. The facility is not designed to allow for the addition of fissile material needed to turn the neutrons produced by fusion into the thermal energy required to turn a turbine. Another experimental facility capable of producing just as much laser energy—and containing some expensive, as yet unproven additions—will need to be built. Work aimed at taking that next step is already proceeding through a project called Laser Inertial Fusion-Fission Energy, or LIFE, which is now running in parallel with NIF.

The DOE scientist thinks the 10- to 15-year time frame is overly optimistic. "It takes about eight years to build a nuclear power plant, and we already know how to put those together," he says.

—Willie D. Jones

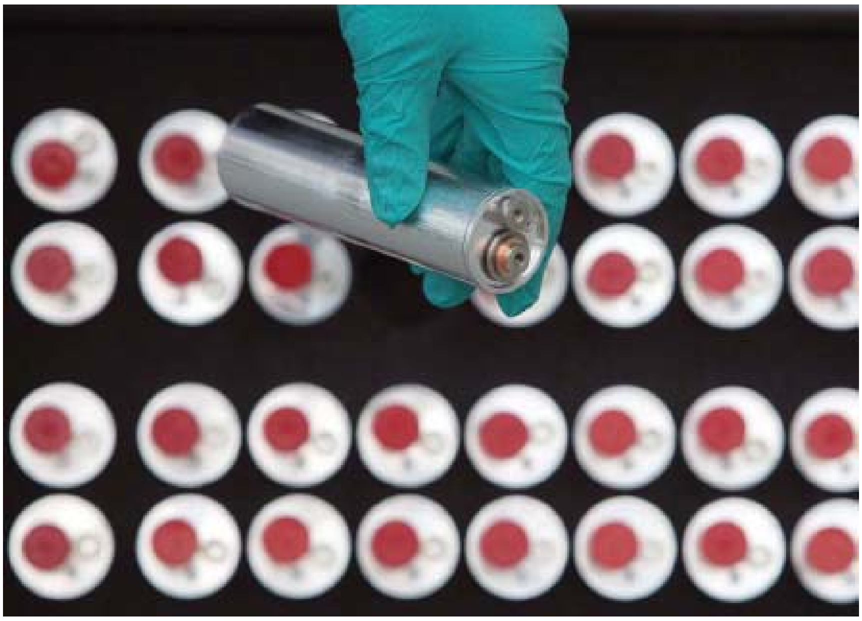
Although the United States is home to attention-getting lithium-ion start-ups, including venture-funded A123 Systems, these firms currently lack the domestic manufacturing capacity to supply automakers. But cell makers understand the importance of manufacturing near their customers; A123 Systems promises plants in southeast Michigan if it receives funding. And in October, 14 U.S.-based battery makers formed the National Alliance for Advanced Transportation Battery Cell Manufacturers, joining a chorus of other advocates for policies that will build a local cell supply base.

"We have a perfect window of opportunity to create a U.S. infrastructure," says Wright. "We have the technology, we will have the customers, and we know how to make cells." Cell manufacturing plants take two to three years to come onstream, so plants funded this year might supply cars for model year 2013. But, Wright says, it has to happen now. "I don't think we even have a year" to ensure that U.S. plants are built on the same timeline as those now planned in other regions, she says.

Already, advocates can point to pending government help in the form of low-interest loans for producers and tax credits for consumers contained within recent finance and energy bills.

Asked to handicap the chance that the United States will get lithium-cell plants, Tony Posawatz, vehicle line director for the Chevrolet Volt, and a man who is intimately enmeshed in the politics of electric-car manufacturing, smiles broadly. "I think from April to June you'll see a lot happening," he says.

—John Voelcker



FRENCH FACTORY: The nearest manufacturer to the United States of lithium-ion batteries for hybrids is Johnson Controls-Saft's plant in Nersac, France. PHOTO: REGIS DUVIGNAU/REUTERS

update

SLAYING DRAGONS: Online fantasy games are just a phone call away.
PHOTO: CHRIS STEIN/GETTY IMAGES

Cloud Computing's Killer App: Gaming

AMD's proposed online supercomputer will handle gaming graphics so your cellphone won't have to

IN RECOGNITION of the huge importance of graphics and gaming to the future of computing, Advanced Micro Devices (AMD), of Sunnyvale, Calif., is building the fastest commercial supercomputer in the world and selling its use to makers of online games. When it's ready, in the second half of 2009, it will manage a thousand million million floating-point operations per second—a petaflop. That will put it on a par with Roadrunner, the U.S. Department of Energy's most powerful machine.

The idea is to compute a game's graphics, compress them, and send them out over the Internet so that online gamers can run the results on platforms, such as cellphones, that are too computationally puny to render the graphics on their own. Game makers would write their software for the supercomputer—rather than for a PC, smart phone, or other platform—and then rent computer time and bandwidth on AMD's machine. It's a particularly striking example of the shift in the balance of power away from the platform and into the network, or cloud—hence the computer's name, the Fusion Render Cloud.

Cloud computing makes it ridiculously easy for potential customers to try out a game and get hooked—all they have to do is go to a Web site and start playing. Another plus is that by off-loading most of the computational guts, cloud computing puts game software out of the reach of pirates. And it economizes on computation time by supplying users with only as much graphical detail as the available bandwidth can handle, when it can handle it.

"We'll be able to render 30 to 50 frames per second remotely and stream it to any modern Web browser," says Jules Urbach, chief executive of Otoy International, the game technology company that's writing the software. "If you're on a low-band phone, we'd send less data per frame—for a lower-res image—but you'd still get 30 to 50 frames per second." The system tests the connection throughout a session, so if the user changes to a more capacious network—say, by switching from a cellphone to a hard-wired desktop—the system responds by adding detail.

The supercomputer will consist mainly of 1000 graphics-processing units (GPUs), each of which can run 800 concurrent computational tasks, or threads. At two chips per graphics card, that means 1600 threads at a pop. About a quarter of the chips will compress or decompress data, and the rest will render the graphics. That's more than enough muscle, AMD says, to serve the players in any existing massively multiplayer game. The company says it can scale up the machine simply by adding more cards.

AMD says the Fusion Cloud will consume only 150 kilowatts running full tilt, compared to Roadrunner's 2.35 megawatts. AMD says it will be able to perform as many operations per second as Roadrunner with less power, because its GPUs, with their hundreds of cores, can do far more things at once than can central-processing units (CPUs), which have only a handful of cores. That allows GPUs to better render graphics, a task best handled by dividing it up and working on the pieces in parallel.

The Fusion Cloud is happening now because three things fell into place only recently. Rapid-access memory reached the gigabyte range; a way of getting GPUs to perform floating-point operations—long the domain of CPUs—was found; and the rendering of subtle shades of light got much easier to program. "Graphics cards originally had no shaders," explains Urbach. "Then they got geometry shading and then pixel shading, an enormous leap. Finally, since June of last year, we've had a general-purpose shader."

AMD's plan is merely a battle in a larger war being fought by Intel, AMD, and Nvidia Corp. over the advantages of graphics processing. "We compete against Intel on the CPU side—they're trying to get their CPUs to be more parallel—and against Nvidia on the GPU side—they're trying to get their GPUs to be more flexible," says AMD spokesman David Nalasco. "We have both."

—PHILIP E. ROSS

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640 gigabits per second The record-setting bandwidth of an optical receiver chip developed at the Australian National University, in Canberra

A Stowaway Mission to the Moon

NASA's LCROSS lunar impactor mission comes in on time and on budget

SEVERAL MONTHS from now, the empty upper stage of an Atlas V rocket will slam into a shadowy crater near the north pole of the moon, tossing a plume of debris up into the sunlight. By then, the Atlas V will have delivered its main payload, the Lunar Reconnaissance Orbiter (LRO), and a smaller stowaway. That stowaway satellite will watch the spectacle unfold from above, looking for telltale signs that there's water in the lunar soil, before it, too, crashes into the moon.

NASA's current plan for manned exploration calls for establishing a base near a lunar pole, where indirect evidence suggests that frozen water is trapped in permanent darkness. Scheduled to launch in late April, the Lunar CRater Observation and Sensing Satellite mission, or LCROSS, aims to explore the nature of lunar water and determine whether it's concentrated in small pockets or spread diffusely throughout the shadowed regions. Although these findings will help guide the strategy of lunar exploration, LCROSS is not a typical NASA mission—it wasn't even on the drawing board three years ago.

"This was probably the ultimate mission of opportunity," says LCROSS project manager Dan Andrews. "Frankly, it was never supposed to happen."

LCROSS owes its existence to the ballooning size of the US $500 million LRO, a lunar-mapping satellite that will scout future landing sites and requires a bigger rocket than originally planned. Even with a larger LRO, the new rocket has more than 1000 kilograms of payload capacity to spare. So, back in January 2006 NASA began canvassing the agency for ideas. Proposed missions had to cost less than $80 million, not interfere with the LRO, and go from concept to flyable spacecraft in less than 30 months.

NASA's missions of opportunity normally involve adding an additional instrument, not building an entirely new spacecraft. So when NASA selected the LCROSS proposal by Northrop Grumman and NASA Ames Research Center in April 2006, the agency designated it a class D mission—one that's allowed a "medium or significant risk of not achieving mission success." The LCROSS team soon realized that their classification, tight schedule, and significant constraints actually freed them from typical NASA methodology, which tends to be risk averse. "We decided that this mission is not about ultimate performance," says Andrews. "It's about cost containment."

To that end, the LCROSS team leveraged proven parts, off-the-shelf components, and previously flight-tested instruments. To reduce the risk of failure, they relied on redundancy. When the empty rocket-stage belly flops onto the soft surface, its shepherding spacecraft will be watching with five cameras, three spectrometers, and one high-speed photometer.

To keep LCROSS as simple as possible, the engineers designed the satellite so that it would be free of moving parts. To point the antenna, for example, technicians will simply turn the entire body of the craft. And LCROSS has no onboard storage devices, so all data will be streamed back to Earth live, including a video feed available to the public.

So far, doing things differently has paid off: When the original launch date of October 2008 rolled around, LCROSS was on budget and ready to go. (Problems with the Atlas V rocket motor have held up the launch.) The agency's ability to stick to schedule and budget is a rare feat that's generated excitement within the space community.

"If LCROSS is successful, I think it's likely that you'll see more of this," says Bruce Betts, the project director for the Planetary Society. But extra launch capacity is a rare luxury, and space exploration is inherently hard and expensive, he says. "You can't take this idea too far."

Andrews agrees that there will always be a place at NASA for big projects. Without them, he says, the facilities and equipment that made LCROSS possible wouldn't exist in the first place. But he hopes LCROSS will prove to the agency that other types of missions are possible.

—JOSHUA J. ROMERO

MOONBOUND: LCROSS is set to smack into the moon.
ILLUSTRATION: NASA

update

Sign Language by Cellphone

Software tricks will let the deaf sign over smart phones

In the past, engineers working on technology to aid the deaf had focused primarily on hearing devices, such as hearing aids and cochlear implants, but recently they've been getting into what's known as deaf technology: applications designed to make the day-to-day lives of the deaf and hearing-impaired easier. Now engineers from the University of Washington, in Seattle, and Cornell University, in Ithaca, N.Y., have taken a big step toward developing a mobile phone that allows real-time conversations in sign language.

Of course, many in the deaf community already use mobile phones to communicate via text messaging and e-mail, but deaf people almost always prefer sign language: It's faster and more natural, just as speaking is easier than writing for most hearing people. Laptops are getting smaller and more portable, making video chats outside the home possible, but Wi-Fi–enabled cellphones would provide even more freedom. When cellphones became capable of video sharing a few years ago, Eve Riskin, Sheila Hemami, and Richard Ladner, all newly minted IEEE Fellows, felt the time seemed right to develop a sign-language-capable phone. "Today's world is more connected by cellphones than by any other device," says the University of Washington's Ladner, whose parents were deaf.

SIGN OF THE TIMES: mobileASL brings signing to the cellphone.
PHOTO: UNIVERSITY OF WASHINGTON

From the beginning, the researchers knew that their project, which they named mobileASL (for mobile American Sign Language), would be a challenge. The low bandwidth available on wireless networks in the United States forced them into the balancing act between speed and quality that's familiar to anyone who works with video, but there was an added twist. Most compression algorithms don't focus on the aspects of video that would make ASL easily understandable, says Riskin, an electrical engineering professor at the University of Washington.

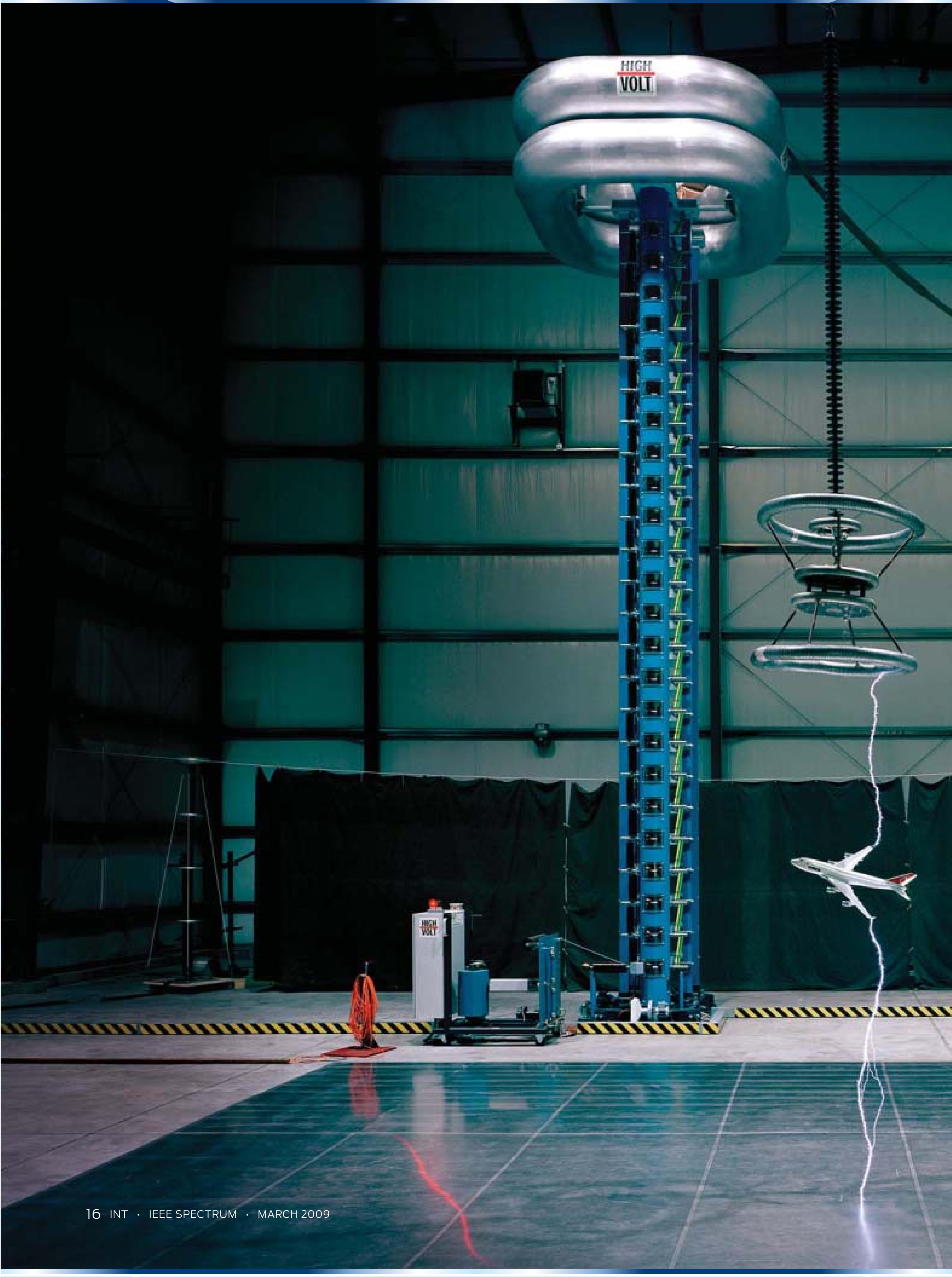
Hemami studies how the human visual system understands video at Cornell University. To help solve the problem, she has been working on integrating an intelligibility metric into the team's video-compression software that would enable mobileASL phones to maximize comprehension. It accomplishes this, in part, by recognizing which areas of the image need to be in high resolution—such as the signers' hands and faces—and which areas, such as the signers' torsos, can be in low resolution.

The team also had to figure out how to preserve the phone's battery life in the face of the power-draining compression and decompression that conversing by video requires. They tackled this problem by implementing a variable frame-rate system that oscillates between high and low frame rates depending on whether the user is signing or watching the other person sign.

Now, nearly four years after they began, the researchers are finally close to a functional prototype. A few months ago, Riskin and her lab at the University of Washington figured out how to increase the frame rates to more than 10 frames per second, a critical step for making mobile video conversations clear and realistic. The mobile phones they were working with weren't capable of processing full-size images at that rate, but by sampling only a quarter of the pixels in each frame, the group was able to make the video-compression process about four times as fast. Fortunately, the interpolation feature in the Microsoft Windows Mobile operating system automatically expanded the resulting videos back to full size without a significant decrease in quality.

The team still faces one big challenge, which is finding the best way to get the mobileASL software into the hands of the people who want it. The group wants the application to be as broadly usable as possible. They are testing it over a Wi-Fi connection but are also experimenting with the data services of several wireless carriers.

—Erica Westly



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the big picture

IN FRANKENSTEIN'S LABORATORY

At the cavernous lab of Lightning Technologies, in Pittsfield, Mass., you first hear a horn's warning blast, then a huge *kapow*. That's the sound that electrons make when 2.4 million volts send them burning a zigzag path through the air. The bolt proceeds from the hanging double corona ring to a model supplied by one of the lab's clients, in this case an airline that needs to test how lightning affects its planes' ever more pervasive electronic control systems. (If you're a frequent flier, you've surely been zinged by Zeus several times already.)

The blue tower consists of a stack of capacitors separated by spark gaps. It takes five or 10 minutes to charge all the capacitors, but when they're ready, a single spark jumping a single gap is all it takes to start the avalanche of electrons.

PHOTO: BOB O'CONNOR

hands on

FUSION ON A BUDGET

Building your own nuclear fusion reactor is easier than you think

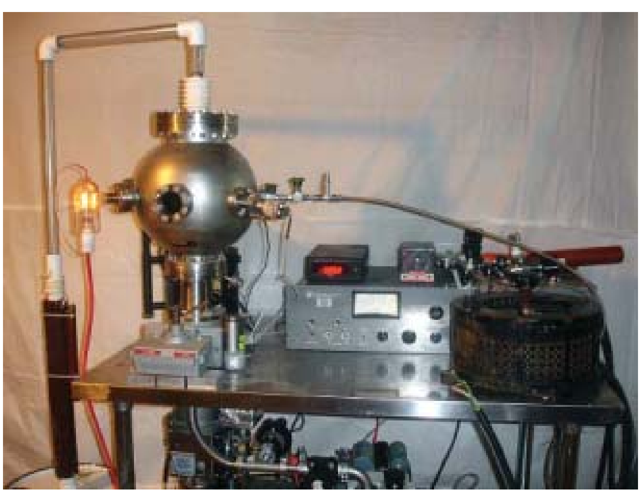
Do you have a few thousand dollars to spare, some basic machining and welding skills, and the ability to follow directions without getting fingerprints inside your equipment? Then you, too, can build a baby fusion reactor, or fusor, in your garage.

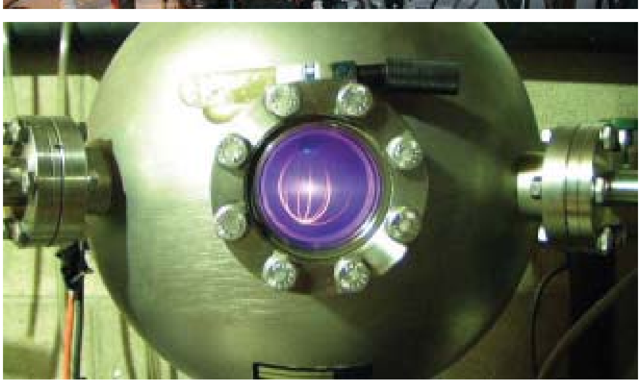
In fact, it's pretty simple, according to Paul Schatzkin, who runs Fusor.net, a Web site where amateur "fusioneers" congregate to swap equipment and advice: "Find two stainless steel half-spheres, seal them together around a wire grid, suck the air out of it, apply some high voltage to the grid, inject a bit of deuterium into the chamber, and sit back and count the neutrons." Don't expect to reach energy breakeven, Schatzkin says, but at least you'll be failing to achieve practical fusion at only a millionth the cost of a tokamak.

Tokamaks, the multibillion-dollar fusion reactors that have occupied physicists' attention for more than 50 years in their quest for limitless clean energy, use a magnetic field to confine a plasma heated to about 100 million kelvins and compressed so that the deuterium nuclei inside will collide and fuse. A fusor is even simpler: Just make a very deep electrostatic potential well for your nuclei to fall into, and make it radially symmetrical so that they wallop into each other when they reach the middle [see "Fusioneering" and "Tabletop Fusion"]. Nuclei at a temperature of 100 million kelvins have the same energy as those that have traversed a potential drop of only about 9000 volts, so getting your nuclei to travel fast enough will not be a problem.

The idea comes from Philo Farnsworth, the inventor of the modern television, who, along with Robert Hirsch, built his first fusor in the mid- to late 1960s.

Since then, professional and amateur researchers alike have found more than enough other problems to make personal fusion reactors a matter of research interest only. The list of issues under discussion by participants in the online community at Fusor.net is well-nigh endless: not enough ion density, too much energy spent in creating ions, ion and electron collisions with the charged grids that create the potential wells, grids melting under the resulting current, vacuum systems that won't evacuate, and so on. Still the fusioneers press onward, motivated by both the simple love of tinkering and the dream





FUSIONEERING: Richard Hull [above] hosts an annual gathering of fusioneers at his lab in Richmond, Va.

Eric Stroud's 30-centimeter fusor [left, top] is typical of reactors built by amateurs. The brown stalk at far left is the high-voltage ballast resistor. The glowing bulb next to it is a hot cathode gauge for measuring deep vacuum. The vacuum meters indicate high-vacuum conditions approaching 1 x 10^{-6} torr.

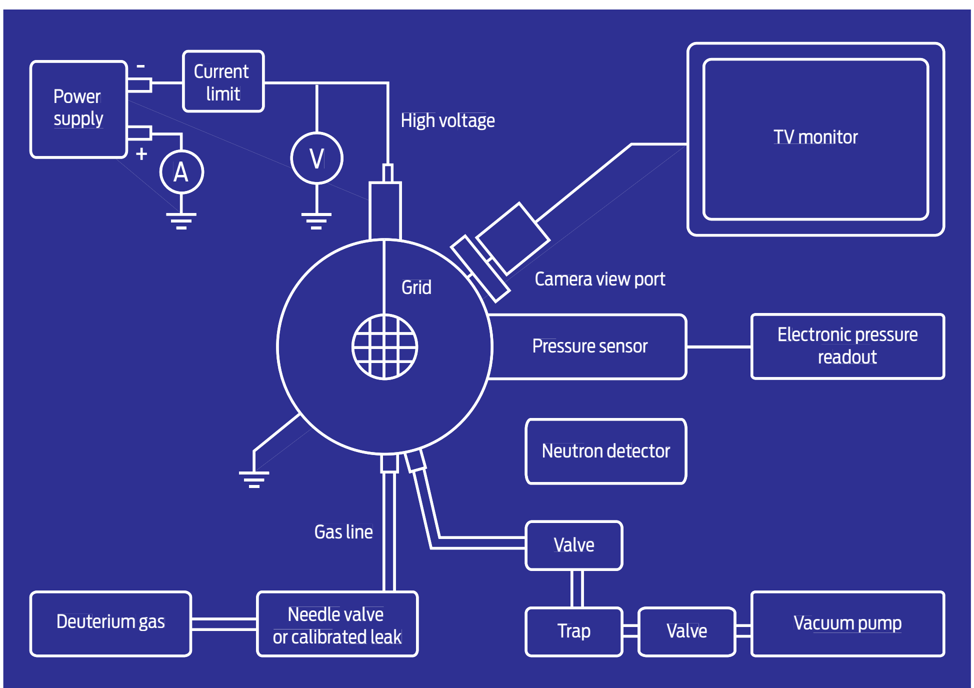
If fusors aren't energy-efficient, they can at least be beautiful. A star-mode plasma [left, bottom] is not only visually spectacular, it also indicates good vacuum, gas control, and neutron production. PHOTOS: ABOVE, RICHARD HULL; LEFT, ERIC STROUD (2)

of contributing in some small way to solving the world's energy problems.

Building a fusor is simple enough for amateurs to contemplate because of the enormous global inventory of used lab equipment, says veteran fusioneer Richard Hull. For example, fusion containers need only achieve pressures of about one millitorr; vacuum pumps with that capability make their way to eBay for US $10 to $100. High-voltage feedthroughs are in the same range—or free, if you build your own from microwave-oven salvage. The most expensive items, according to Schatzkin, are neutron detectors, which have to be purchased new. But a cheap workaround is available, Hull says: You can prove your fusor is working by irradiating a piece of silver and watching the decay of the Ag-108 and Ag-110 isotopes with a simple Geiger counter.

What is the fusor good for, other than the smugness of knowing that you've turned hydrogen into helium in quantities almost too small to detect? Nothing at all, says Hull. Although some amateur fusioneers write as if their work might eventually lead to useful power generation, he's convinced that this quest is well beyond the horizon. And although neutron activation of other elements, such as aluminum, iodine, or gold, is a neat parlor trick, if you actually got enough of some longer-lived isotope to do something useful with it, you'd need a federal license, pronto.

—Paul Wallich



TABLETOP FUSION: To make a fusor work, the vacuum chamber and high-voltage accelerating grid inside it must be augmented with both a vacuum system [lower left] to remove air and a deuterium feed. The neutron detector is the final arbiter of when atoms have fused, but a view port may be crucial for observing the behavior of gases inside the chamber while debugging the fusor.

FIVE EASY STEPS TO HOME FUSION

1 CHOOSE YOUR FUSOR DESIGN: Hirsch-Farnsworth [see "Tabletop Fusion"], Elmore-Tuck-Watson, or some variant of your own creation.

2 ASSEMBLE YOUR FUSOR with a fanatical attention to cleanliness. You will need a vacuum-tight shell, a high-voltage grill, various feedthroughs, a valve to admit deuterium, a vacuum pump, and power supplies.

3 PUMP THE FUSOR down to a millionth of an atmosphere or so, fire it up to 10 or 15 kilovolts (or whatever levels your design requires), and see what kinds of discharge it makes without deuterium in it. There are images on fusor sites to suggest what you ought to be seeing; if you aren't, debug until you are.

4 ACQUIRE SOME DEUTERIUM (either as a gas or as heavy water that you can split by electrolysis), some sensors for detecting neutrons or charged particles, and some shielding.

5 TURN ON your fusor, admit trace quantities of deuterium from a safe distance, and collect your data.

—*P.W.*

careers

FOREIGN AFFAIR

Working abroad can make you a better engineer everywhere

IN HIS 14-year career as an industrial and electrical engineer, Carlos Founaud has worked or done business in Austria, Switzerland, Ireland, Portugal, Germany, Britain, Australia, and Italy before returning to his native Spain.

"I called myself a multicultural interface," he laughs. "If something broke down, the Spanish way was to focus on the problem—let's have a look, make a decision, and do it. The Austrian way was to find out who's guilty. The British way was to open the manuals and find the different procedures for fixing it—and afterward go to the pub."

Founaud has found that this multicultural approach to problem solving, while maddening at times, has also made him better at his job. Now general managing director of iA Soft Aragón, a Saragossa firm that develops public administration software, he seeks out foreign programmers specifically to challenge the procedural mind-set on his home turf.

Foreign postings often offer more autonomy and responsibility, a faster pace, higher pay, and tax breaks, as well as the adventure of foreign lands and languages. The posts can also improve your skills.

"I believe working abroad exposes you to new technologies and creative approaches, and working with multicultural teams makes you more flexible," Founaud says. "You have to cope with ways of thinking that you could never imagine"—like thinking ahead to your next gig. "Nobody is going to promise you a job when you return," he notes. "Things change so quickly in engineering; companies go up and down. Decisions promised today are not valid tomorrow, and contracts don't mean anything. You have to look at going abroad as an adventure."

Robert Brems, a mechanical engineer based in Coshocton, Ohio, agrees: "Out of sight, out of mind. You might miss advancement opportunities and become vulnerable to layoffs if your position ends." Before retiring four years ago, Brems worked on nuclear power plants in Korea, Yugoslavia, and Slovenia for engineering firm Gilbert/Commonwealth, formerly based in Reading, Pa., and now part of the Australian engineering conglomerate WorleyParsons.

"Job insecurity is one of the dangers of being abroad," concedes Jaime H. de Sola, an MIT-educated chemical engineer who runs an energy industry consultancy from his native Curaçao, an island in the Netherlands Antilles in the Caribbean. He spent years in India, the Netherlands, Russia and Eastern Europe, Venezuela, and the United States working for Shell, Hess, and Amoco. But, he says, "if you do a good job in a difficult place, the company will be grateful." He says oil companies in particular are accustomed to sending people abroad, "so I've seldom heard of their employees coming back to no job position."

The engineering sector determines the prestige of the post, says Founaud. For electrical engineers working on electronic clocks, a Geneva firm is prestigious. There's San Jose, Calif., for IT, Qatar for gas, and Austria for gas engines, while Germany, Switzerland, London, and New York City have cachet for managers. But Brems notes that as more countries develop local engineering capabilities, overseas posts are increasingly located in rural parts of developing nations, which raises concerns about substandard health care and living conditions.

Companies generally provide assistance looking for houses and schools. It helps if you have an adaptable spouse and younger children, as education may be less stable with changing posts. Founaud returned home because he wanted educational stability for his children once they entered grammar school. But it was his multinational work experience that landed him his current job.

"That experience working as a cultural interface is what brought me to this IT company," he says. "The owner wanted someone who could deal with different cultural mind-sets. That experience was my 'value added'—not the knowledge of the customer, sector, or technology." —SUSAN KARLIN

KEVIN VAN AELST

THROWING PHYSICS A CURVE

David Peters studies the aerodynamics of baseballs and helicopters

It's March, and that means two things for David Peters—the start of the baseball season and appearing on television. Ever since his hometown St. Louis Cardinals won the 2006 World Series, he's appeared regularly on local news to explain the mechanics behind curveballs and suchlike.

"I'm a ham—I don't mind being the center of attention," he says, laughing. "And it gives us a hook for explaining science to the public."

Peters holds a Ph.D. in aeronautics and astronautics from Stanford, worked for McDonnell-Douglas on the Apollo and Skylab space programs, and serves as the McDonnell-Douglas Professor of Engineering at Washington University in St. Louis. But he's best known for the Pitt-Peters model, which helicopter flight simulators use to describe rotor-induced airflow in real time. And he brings the same high-tech creativity to the ballpark.

"Modern computational fluid dynamics codes can successfully predict the pressures and resultant motions of a baseball, just as they can for a F-18 fighter," Peters says. "The codes can predict the different motions of a curveball, fastball, knuckleball, slider, or changeup, since each has a different spin that results in a different pressure and flow field. These types of predictions were not possible until recently. Based on this, some Japanese aerospace engineers have been trying to use aerospace theory to develop a brand-new pitch."

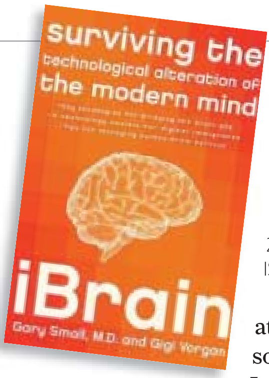
—Susan Karlin

See Peters in action at http://news-info.wustl.edu/tips/page/normal/12487.html.

WASHINGTON UNIVERSITY IN ST. LOUIS

books

THIS IS YOUR BRAIN ON GOOGLE



iBRAIN: SURVIVING THE TECHNOLOGICAL ALTERATION OF THE MODERN MIND
By Gary Small & Gigi Vorgan;
Collins Living, 2008;
256 pp.; US $24.95;
ISBN: 978-0-06-134033-8

Psychiatrist and neuroscientist Gary Small, of the University of California at Los Angeles, invented the first brain scan that showed physical evidence of brain aging and Alzheimer's disease in living patients. He's since focused his research on young and old brains, revealing that technological overexposure causes significant changes in neural circuitry. In his 2008 book *iBrain: Surviving the Technological Alteration of the Modern Mind*, he reports that Web surfing, multitasking, and information bombardment can accelerate learning and creativity but may also increase attention deficit disorder, social isolation, and Internet addiction.

Small, the director of the UCLA Memory and Aging Center, used functional MRI scans to track brain blood flow in middle-aged and older adults surfing the Web. He noted that Internet searching stimulates frontal lobe circuits, which are responsible for decision making. Other studies suggest that video gaming both increases and decreases activity in the frontal lobe and the amygdala, which handles emotional response, thereby decreasing social interactivity. "Technology is not only changing our lives; it's changing our brains," says Small.

Here are some suggestions Small offers to ward off techno-overload:

1) Vary tasks at a reasonable pace. Switching tasks too often slows down brain efficiency over time, while continuing a single task for too long can fatigue the brain. For example, instead of tackling all your e-mail at once, take a break after 20 or 30 minutes, and complete the rest later in the day. Although you may feel as though you are getting more done, rapidly alternating tasks is less efficient and leads to errors.

2) Set boundaries. Limit the time you will spend using cellphones, computers, and video games.

3) Balance on- and offline time. Tackle business and creative issues both technologically and socially through in-person and online collaborations.

4) In other words, go outside. Hang out with your friends and colleagues—in person.

—Susan Karlin

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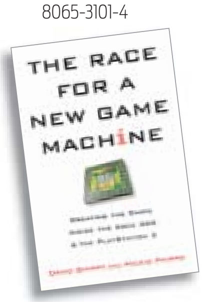
tools & toys

books

THE RACE FOR A NEW GAME MACHINE: CREATING THE CHIPS INSIDE THE XBOX 360 AND THE PLAYSTATION 3
By David Shippy & Mickie Phipps; Citadel Press, 2009; 256 pp.; US $21.95; ISBN: 978-0-8065-3101-4



One of the great business stories of our young century lies buried within the 74 million video-game machines sold in the past three years. IBM began by making microprocessors only for Nintendo, but now it also supplies the ones inside the Sony PlayStation 3 and the Xbox 360.

A new tell-all business book, *The Race for a New Game Machine*, documents that industry transformation. The authors—David Shippy, chief architect of the microprocessor core, and project manager Mickie Phipps—cast blame and credit equally, letting the chips, so to speak, fall where they may.

—Steven Cherry

ELP LASER TURNTABLE
US $10 990–$14 990
http://www.elpj.com

GIVE YOUR RECORDS A BREAK

Old LPs can sound as good as new—even when cracked in half

Last year, vinyl record sales rose 15 percent while the rest of the music industry kept on tanking. Like Converse sneakers, the LP has a way of sticking around long after obsolescence—and even, somehow, maintaining an aura of cool.

Now another old technology, the laser turntable, is making a comeback too. Manufactured by ELP Corp., in Saitama, Japan, it uses five lasers instead of a physical tone arm and stylus, and it can do something no stylus can: play a broken record.

John Hora, a retired cinematographer and lifelong classical music buff who owns two laser turntables, saw this firsthand. One day, in a Los Angeles thrift store, he found violinist Albert Spalding's performance of Johannes Brahms's *Hungarian Dances*, an LP he had sought for decades. Because the record had broken into two pieces, the store's owner let him have it for free. He took the pieces home, laid them on the laser turntable's platter, and pressed *play*. "It was thrilling being able to play a broken record," he says.

Proponents claim that these devices—bearing hefty price tags of US $10 990 to $14 990—can capture the warmth of vinyl while still hitting every frequency and harmonic preserved in the groove's ridges with a CD's cold precision. Unfortunately, the turntable's sophisticated optics will also pick up dust and grime too small to move a stylus needle. So to reduce vinyl's trademark pops and crackles, the listener has to clean the record carefully, typically with a special device that can cost upwards of $500. Further noise reduction mandates an external on-the-fly "declicker" signal processing box, which itself costs about $2800. Little wonder then, that with starter kits running into five figures, the laser turntable is a high-end boutique item that won't be sold at your neighborhood Best Buy anytime soon.

The laser turntable was originally patented in 1988 as the Finial by Stanford engineers Robert Stoddard and Robert Stark. A year later, they sold the rights to electronics company CTI Japan. After some further handoffs, ELP began selling its LT series of turntables in 1991. Eighteen years later, a mere 1500 have been purchased worldwide, mostly in Japan. The more expensive models play at 78 revolutions per minute, as well as 33 and 45, and can handle a greater variety of disk sizes.

But as CD sales plummet and vinyl enjoys its own small bounce, ELP's American vice president, Jim Peek, hopes to capitalize on the old medium's resurgence. Twenty percent of ELP queries, he says, come from the twentysomething generation of vinyl enthusiasts.

Hora, who boasts 38 000 LPs in his collection, says what draws him to high-end turntables—both laser and mechanical—is his deep love for the music and his desire to reproduce it as perfectly as technology will allow. "I mostly talk to other record collectors," he says, "and I don't have to explain myself." —Mark Anderson

TOP: ELP CORP.; BOTTOM: JONATHAN KANTOR/GETTY IMAGES

reflections

BY ROBERT W. LUCKY

JONATHAN CARLSON

The Dreaded Computer Upgrade

EVERY TECHIE'S heart beats a little more quickly at the thought of a new electronic gizmo. In the case of a computer, however, this anticipation is muted by several dark thoughts.

First, the new computer isn't really going to do anything different than the beloved old one, just the same things a little faster. And that modest increase in speed is going to come at an enormous cost in worry—and the work of switching over to the new machine. Fortunately, we don't replace computers very often these days. Processor speeds have plateaued. We've improved performance through multiple processing cores, but so far we haven't done much to use them. And how many cores do you need to run a word processor or a Web browser anyway?

This present hiatus is a grave problem for the industry, and by implication, for all us electrical engineers. Nevertheless, it isn't my concern today; eventually, an old computer must be replaced, if for no other reason than that the only operating systems it can run are no longer supported. What I want to talk about is that dreaded cutover. Just the thought of having to transfer everything from the old machine takes the shine off my glittering new one.

So I sit at my old computer, while over in the corner is a half-opened box. My whole life—hundreds of apps holding together more than a terabyte of data—is in this familiar old machine. I don't even know what's in there anymore. I'm trying to save everything to external drives and DVDs, but even if I succeed, all the applications will have to be reinstalled. I may not be able to find the original disks, and they may not work with the new operating system. What a nightmare!

With what I hope is all my data in hand, I crawl into the dark confined space behind my computer, where lies a rat's nest of dusty, tangled wires coming from unknown places and leading to other unknown places. This is it—the point of no return. I start to unplug everything.

Now I get to my main worry. This is an irrational worry—or maybe too rational, being a worry that I think only a techie would have. Or perhaps I'm the only one in the world who thinks this way, but I'm worried that the new machine won't work. I have visions of having to box the thing back up and take it back to the store, where they'll look at me like I'm a klutz who doesn't know how to plug in a computer. And I've already committed to the new lemon. The prospect of going back to the old machine is now unbearable.

I can't help but think about all the things that have to function perfectly for this new computer to work. The processor has hundreds of millions of transistors—even more in the memory. And all those interconnections onboard the chips! The backplane has hundreds of tiny mechanical connections. The hard drive has a head that floats less than a micrometer above a spinning disk, which in turn has magnetic domains of similar minute size. There are literally billions of single points of possible failure. There is no way that this new computer will work. I'm doomed.

Amid such thoughts, my finger hesitates on the power button. There is already a little light glowing inside the new machine. At least it knows it's connected to power. Big deal.

I hold my breath and push the button. I hear the roar of a fan. That's a start. Nothing yet on the screen. Suddenly, there is life! I see the manufacturer's logo on the screen! I'm still scared, but probably irrationally so. Although I'm only looking at an output from the motherboard's basic input/output system, for this logo to appear on the monitor, almost everything in the computer has to work. From a hardware standpoint, only the hard drive has yet to prove itself.

Now the screen goes blank. This is the most frightening time of all. Is it going to come back to life, or is this the end? The blankness lasts forever—maybe longer. But after an eternity I see the welcome screen from the operating system. I collapse in relief. All I have to do now is to re-create my entire computing environment. This will be arduous, but at least I will be in control.

I don't know how many more times I can do this. ❑

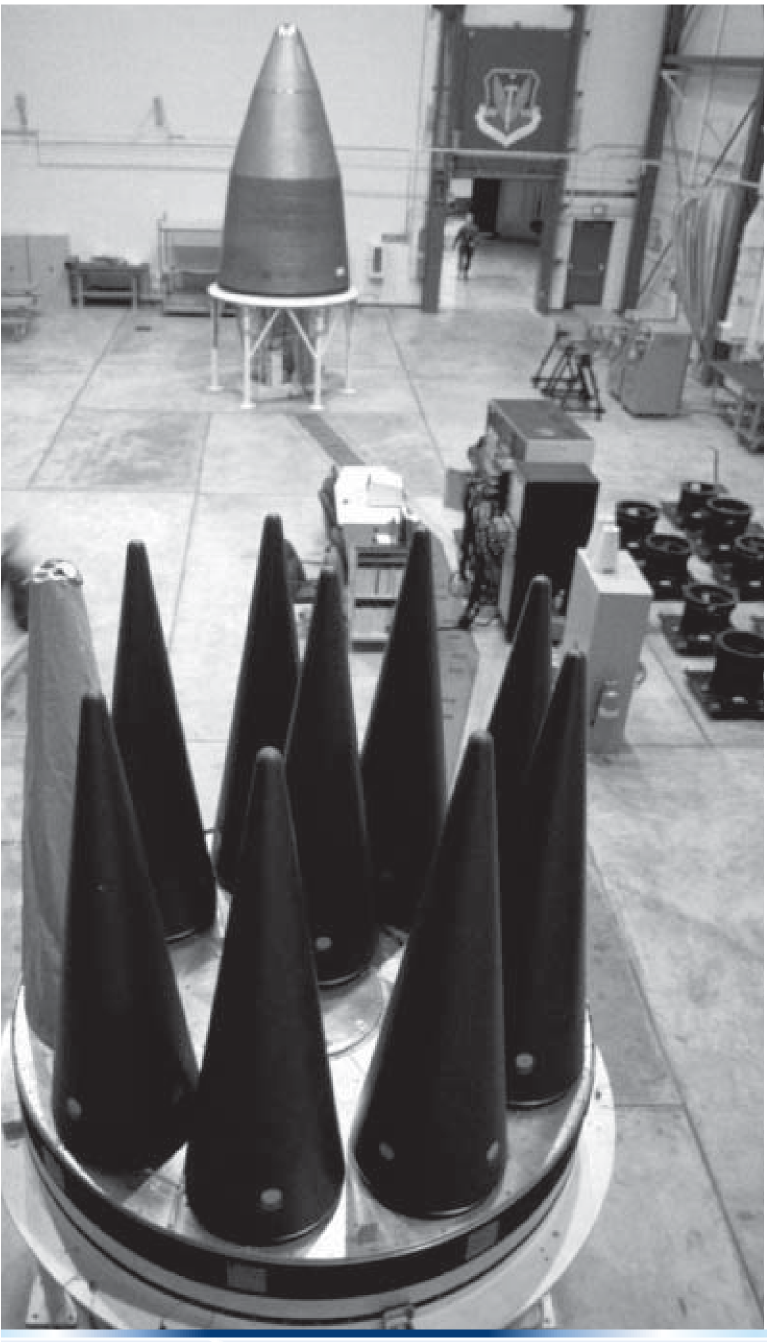
WHAT ABOUT THE NUKES?

THE U.S. NUCLEAR STOCKPILE IS SHOWING ITS AGE, BUT BUILDING NEW WARHEADS ISN'T THE SOLUTION

BY FRANCIS SLAKEY & BENN TANNENBAUM

STILL WAITING: Warheads for Peacekeeper missiles sit at Warren Air Force Base, Wyo.
PHOTO: PAUL SHAMBROOM

READY OR NOT: Nuclear gravity bombs at Barksdale Air Force Base, La., are among the 5200 warheads in the U.S. nuclear stockpile.
PHOTO: PAUL SHAMBROOM



The United States' thousands of nuclear warheads have the explosive equivalent of over 1 gigaton of TNT. It's an amount of energy that could literally move mountains, reroute rivers, alter climate, and result in the deaths of hundreds of millions or even billions of people, through fire, radiation, and starvation.

Like everything else on Earth, those warheads are getting older. But unlike anything else on Earth, that mere aging may have profound consequences for the national security of the United States.

Most of the nuclear warheads in the U.S. arsenal date from the late 1970s and the 1980s, with anticipated lifetimes of 20 to 25 years; the most recent ones, the submarine-launched W88s, were added in 1988. Most of the warheads, in other words, are now past or nearing their estimated expiration dates. If nothing is done to maintain these hugely complex systems, they will in time fail, leaving the United States with no nuclear arsenal at all.

In fact, U.S. President Barack Obama has expressed an interest in eliminating all nuclear weapons—eventually. But he has also stated that the United States still needs a nuclear deterrent and that nuclear weapons should remain a key part of its security strategy for the time being.

Officials in the United States and the other seven declared nuclear powers are now grappling with a tricky and essentially unprecedented problem: What is the best way to sustain their nuclear deterrents? The question is particularly urgent in the United States, which has some 5200 functional nuclear warheads, about the same number as Russia, and several thousand more than the sum total of the world's other nuclear arsenals combined.

Since the early 1990s, the prevailing view of nuclear weapons is that they are like other manufactured systems, such as cars and commercial jets. Their various components grow old, and eventually they will become nonfunctional. But that fate can be staved off by routine surveillance and maintenance and occasional replacement of parts or software. Such techniques have successfully extended the life spans of commercial airliners by decades.

But over the past several years, some high-placed U.S. officials, including Defense Secretary Robert Gates, have come around to a different view—that even with diligent inspection and maintenance, the current arsenal will soon become unreliable and will no longer have much deterrent value. The only solution, they say, is to design and build new

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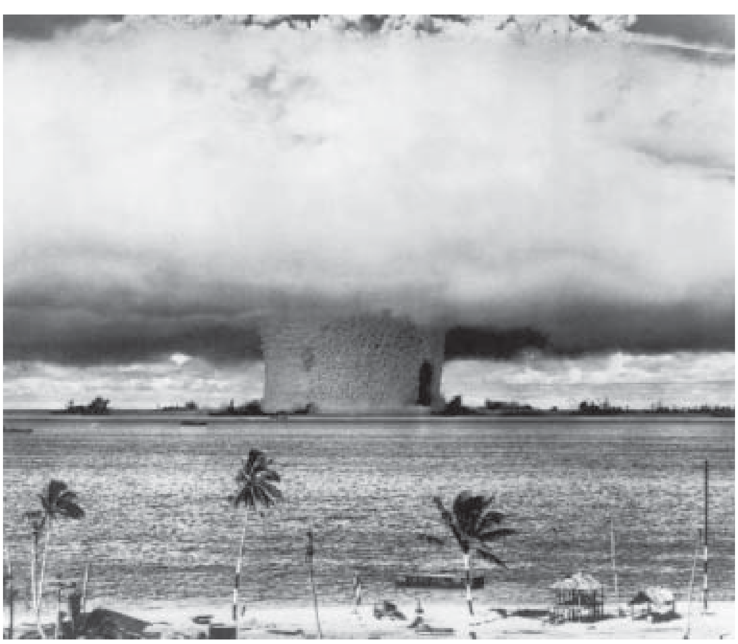
warheads. These new weapons would be produced using state-of-the-art industrial methods that would vastly simplify manufacturing and maintenance and also drive down costs.

Such arguments for new warheads are compelling—but also controversial. Critics note that under the Treaty on the Non-Proliferation of Nuclear Weapons, or NPT, the United States and other nuclear nations are obligated to work toward eliminating their nuclear arsenals. Some even argue that U.S. modernization efforts, though confined so far to paper studies, have encouraged North Korea, Iran, and other countries to redouble their efforts to produce nuclear arsenals of their own. Proponents of building new warheads counter that these systems would simply be replacing antiquated weapons and that over time the total arsenal would continue to shrink.

Geopolitics is an inexact science, to put it mildly. But physics is not, and as physicists who've been involved in science and national security policy for many years, we believe that science and technology can, in this case at least, tell us all we need to know to decide this issue. Based on the available data, we are confident that the current program of stockpile stewardship, with some modifications, can preserve the U.S. arsenal for the foreseeable future and that it isn't necessary—and may even be counterproductive—to pursue new warheads.

What we're *not* saying is that extending the life span of the arsenal is going to be easy. To understand why, you're going to need a quick refresher in nuclear history and technology.

BIG BANG: An atomic bomb blast near Bikini Atoll, one of 1054 nuclear tests the United States conducted between 1945 and 1992.
PHOTO: COURTESY OF NATIONAL NUCLEAR SECURITY ADMINISTRATION/ NEVADA SITE OFFICE



The United States invented nuclear weapons during World War II and used the first ones toward the end of that war, in August 1945, when U.S. forces dropped atomic bombs on the Japanese cities of Hiroshima and Nagasaki. They remain the only nuclear weapons ever used in combat.

Not surprisingly, nuclear weapons quickly gained a central role in U.S. national security policy. A vast and secretive nuclear-weapons complex arose, with the U.S. Department of Defense dictating the military requirements that guided each new warhead design. Designing, building, testing, and stockpiling those warheads fell to the laboratories now operated by the U.S. Department of Energy (DOE)—namely, Lawrence Livermore, Sandia, and Los Alamos—and the weapons-production facilities, including Hanford, Oak Ridge, Rocky Flats, Y-12, Argonne, Savannah River, and Pantex.

Typically, the labs would produce competing designs for a new warhead, of which one would be selected. Los Alamos National Laboratory led the field: Warheads designed there now make up more than 80 percent of the active stockpile [see table, "Warheads Produced at Los Alamos"].

After a design was selected, the first prototypes would be assembled and tested; based on the test results, nuclear designers would refine their creations. Once a design was finalized, the weapons would be built in quantity at one or more of the DOE production facilities, with the final assembly taking place at the Pantex plant, near Amarillo, Texas.

The weapons would be deployed to the services for a typical lifetime of 20 years. (Although the U.S. Army no longer has nuclear forces, the Navy and Air Force still do.) At any given time, the number of weapons deployed or held in reserve depended on the U.S. government's assessment of threats as well as its international treaty obligations. For nearly five decades the United States continued to design, build, and test nuclear weapons, routinely replacing older warheads with newer, more advanced ones.

As in any engineering enterprise, the testing phase was considered crucial. From July 1945 through September 1992, the country performed 1054 nuclear tests. Initially, the detonations occurred above ground, at the Pacific atolls of Bikini and Enewetak and also at the Nevada Test Site in the western United States. After November 1962, U.S. testing moved underground, at the Nevada site.

Then, in 1992, the U.S. government imposed a moratorium on all nuclear testing, which has since been extended indefinitely. Three years earlier, production of the plutonium pits that are at the heart of a warhead had been shut down at the Rocky Flats facility, in Colorado. Because Rocky Flats was responsible for the plutonium pits used in all U.S. warheads, its closure effectively ended the production of new weapons.

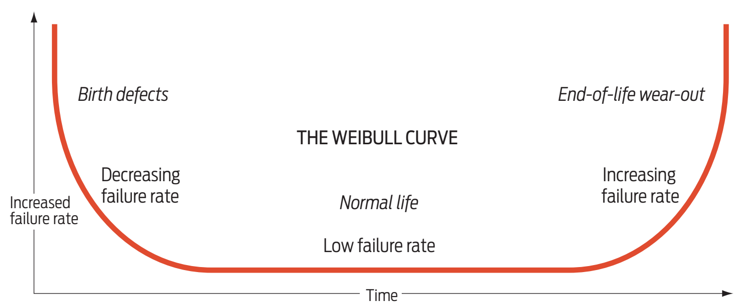
That left nuclear weaponeers with a difficult engineering challenge: Maintain a reliable U.S. arsenal, but do it without building or testing new warheads. The strategy they came up with is called stockpile stewardship.

Surveillance, assessment, and refurbishment are the cornerstones of the Stockpile Stewardship Program, which began in 1993. A sprawling endeavor with activities spread over facilities in seven states [see map, "Stewards of the Stockpile"], the program cost U.S. taxpayers about $6.5 billion last year. Compared

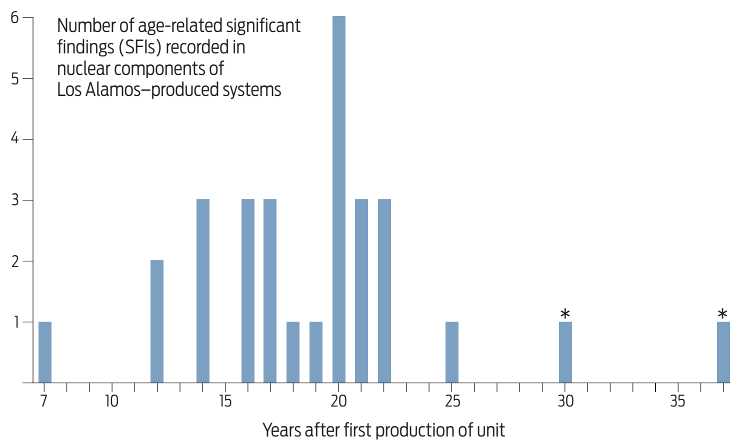
WARHEADS PRODUCED AT LOS ALAMOS

WEAPON	YEAR OF FIRST PRODUCTION	TYPE	NUMBER IN ACTIVE STOCKPILE (estimated)
B61-3	1979	Gravity bomb	200
B61-4	1979	Gravity bomb	200
B61-7	1985	Gravity bomb	215
B61-11*	1996	Gravity bomb (earth penetrator)	20
W76	1978	Submarine-launched ballistic missile	1712
W78	1979	Intercontinental ballistic missile	785
W80-0	1983	Submarine-launched cruise missile	100
W80-1	1981	Air-launched cruise missile	1450
W88	1988	Submarine-launched ballistic missile	404

* The B61-11 is a variant of the older B61. Changes were made to its case and some of the electronics, but the plutonium pit is the same as those used in other B61s. So most nuclear weapons experts consider the W88, not the B61-11, to be the newest U.S. warhead. SOURCE: ADAPTED FROM "NUCLEAR NOTEBOOK," BULLETIN OF THE ATOMIC SCIENTISTS, JANUARY/FEBRUARY 2007; SEE ALSO HTTP://WWW.NRDC.ORG/NUCLEAR/NUDB/DATAB12.ASP



IN THE TUB: The Weibull, or bathtub, curve indicates where a product is in its life span. Nuclear warheads, like other manufactured systems, are believed to follow this curve.



OLD BUT OKAY: Age-related significant findings (SFIs) seen in nuclear components from Los Alamos–produced systems indicate that even the oldest systems are experiencing few problems. [Asterisks indicate weapons that are no longer in the active stockpile.] SOURCE: MARK DOMZALSKI, LOS ALAMOS NATIONAL LABORATORY

to other important infrastructure programs, that's not out of line. The U.S. government spent $195 billion to fix roads and bridges that same year.

The program's simple-sounding name, Stockpile Stewardship, doesn't begin to capture the enormity of the task. Very few systems are engineered to sit inactive for years or decades and then be ready to deploy at just a few moments' notice. Bear in mind, too, that each weapon is extremely complex, incorporating chemical explosives, radioactive materials such as plutonium and tritium, an array of electrical and electronic components, and metal casings, support structures, and more. The failure of any of these would degrade the weapon's performance.

Every year, workers in the Stockpile Stewardship Program systematically inspect 20-plus samples of each type of warhead in the active stockpile. When a problem is spotted, inspectors then decide whether a fix needs to be applied across all similar warhead types. Inspections include destructive test-

HOW NUCLEAR WEAPONS WORK

THE CRITICAL component of any nuclear weapon is the fissile material. This can be highly enriched uranium or plutonium. For the uranium in particular, the material's isotope is crucial. (Recall that the number of neutrons in an atom's nucleus determines the isotope.) For a fission bomb, the most suitable uranium isotope is U-235. For plutonium it's Pu-239.

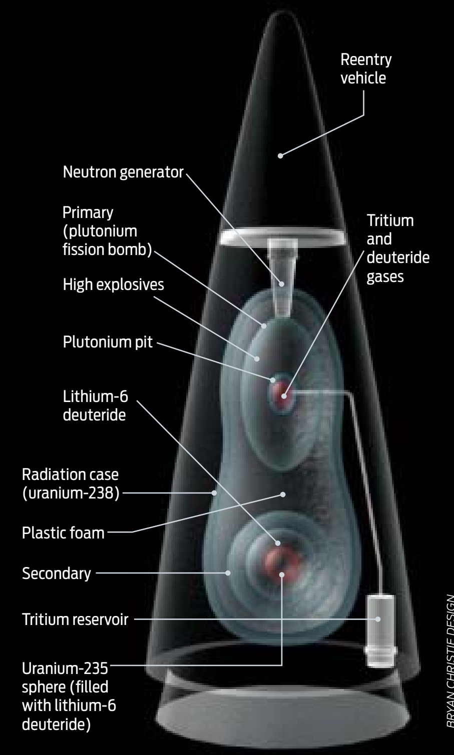
In a fission reaction, the isotope's nucleus is struck by a neutron and splits into two smaller pieces, releasing both energy and additional neutrons. With enough fissile material in a sufficiently compact volume, those additional neutrons will strike other nuclei, causing them to undergo fission and start and sustain a chain reaction.

The nuclear bomb dropped on Hiroshima was a gun-type device, which shot a subcritical mass of uranium into another subcritical mass of uranium; the combination of the two created a supercritical mass. The warhead dropped on Nagasaki, by contrast, was a somewhat more sophisticated implosion device. In this bomb, a conventional high explosive surrounding a plutonium core was detonated, compressing the core and increasing its density. The compression caused the critical mass to be exceeded and, again, a fission reaction resulted. Both bombs used a neutron generator, which releases enough neutrons to kick-start the chain reaction.

A key advance in warhead design came in the early 1950s through the addition of a small amount of a light element, such as lithium or tritium. Known as boosting, this addition causes the plutonium or uranium fuel to burn more completely, increasing the yield of the weapon.

Today's nuclear warheads are known as thermonuclear devices and operate in two stages. In the primary stage, implosion of the boosted plutonium generates enough X-ray energy to ignite a second, much more powerful boosted weapon in the secondary stage.

Throughout the Cold War, the goal for each successive generation of warheads was always to increase the destructiveness of the weapon—known, perhaps euphemistically, as the yield and measured in equivalent tons of TNT—using the same warhead mass. The two weapons used in World War II, for example, had yields of 13 to 21 kilotons of TNT equivalent. In the 1960s the Soviets tested warheads equal to 50 megatons of TNT. *—F.S. & B.T.*



ing of some of the nonnuclear components and nondestructive testing of other components. The exact components inspected and the exact tests performed are classified. But in general, the inspectors look for signs of aging, such as cracks or corrosion. They also use supercomputer simulations to assess the possible impact of any such deterioration on the weapon's safety and reliability.

As you might have guessed, measuring and combating the effects of radiation on the warhead's components is a primary focus of stockpile stewardship. All the components in a warhead are of course designed to withstand a radioactive environment; the computer chips, for example, which control the bomb's fusing, triggering, and detonation, among other things, are all radiation hardened.

A warhead's radioactive materials are also subject to decay. For instance, tritium, a radioactive isotope of hydrogen used in warheads to boost the explosive power, has a half-life of 12.3 years and so must be replaced at regular intervals.

Plutonium-239, the isotope used in nuclear weapons, is a little more hardy; it has a half-life of about 24 000 years. In a weapon, the plutonium is arranged in a grapefruit-size "pit." When a thermonuclear weapon is detonated, chemical high explosives produce a collapsing shock wave that physically compresses the hollow spherical pit. The pit achieves critical mass and, with the help of a neutron generator, begins a runaway fission reaction. The chemical explosives, the pit, and the initiator are collectively known as the weapon's primary. The primary's fission reaction, in turn, produces the extreme temperature and pressure needed to trigger the thermonuclear (fusion) reaction, in the part of the weapon called the secondary, where virtually all the explosive yield of the bomb comes from [for further details, see sidebar, "How Nuclear Weapons Work"].

Scientists used to worry that radioactive decay of the plutonium pit would shorten its useful lifetime. A half-life measured in tens of thousands of years would seem to preclude immediate concern, but the sample does sustain very slight damage each time a plutonium atom decays. That decay releases an alpha particle that slightly displaces a few thousand other plutonium atoms from their original locations. The concern was that these relocations would change the grain structure of the plutonium metal, thereby diminishing its explosive power.

But extensive studies of pits using high-resolution imaging techniques, such as transmission electron microscopy and X-ray photography, and accelerated aging studies using shorter-lived isotopes of plutonium have revealed no significant aging problems. Indeed, based on these findings, a 2007 report by JASON, a distinguished and high-level defense advisory group, concluded that "most primary types have credible minimum lifetimes in excess of 100 years."

Think of an aging weapon as an aging car. Several weapons experts already have, including Stephen M. Younger, president of National Security Technologies, which oversees the Nevada Test Site. In a 1999 paper, he wrote, "Cars age. Materials need to be replaced and batteries wear out. You need to do all sorts of things. Each component has a finite life, although with proper attention the whole system may last for a long time. We have the same situation with nuclear weapons."

Much like an aging sedan, aging warheads undergo regularly scheduled refurbishments and upgrades to correct any problems spotted during the inspections.

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In some cases, a replacement part that no longer exists may need to be remanufactured. Or the manufacturing processes used to produce the part may now be considered too hazardous, such as those involving beryllium, which can cause skin and lung disease. In those instances, specialists need to design a new component and then fabricate it using safer tools and techniques. Still other aging components may be replaced with modern parts. To this day, some weapons still contain vacuum tubes; workers replace these with solid-state electronics.

But not everyone is convinced that the Stockpile Stewardship Program's annual inspections are effective. Especially in the last three years, a number of people at the weapons labs and the National Nuclear Security Administration, which oversees the stewardship program, have raised concerns about its long-term viability. The associate directors of the Los Alamos and Lawrence Livermore laboratories and the vice president of Sandia National Laboratories have all called for a return to designing and building new nuclear weapons, under a program they call the Reliable Replacement Warhead (RRW).

> WHILE THE STOCKPILE IS UNDOUBTEDLY AGING, IT DOESN'T APPEAR TO BE CLOSE TO THE END OF ITS USEFUL LIFE

TECHNOLOGY HAS COME a long way since the last U.S. nuclear weapons were designed in the mid '80s. For that and other reasons, new weapons built under the RRW effort would be vastly superior to the current stockpile, proponents argue. Their designs would emphasize safety, security, and reliability, rather than just maximum explosive power. The new warheads would also be simpler and cheaper to construct and maintain, and they would allow for the use of modern manufacturing techniques, rather than the comparatively costly and dangerous processes used during the Cold War. The RRW program would also train a new generation of U.S. weapons designers.

After considerable debate, the Nuclear Weapons Council, which consists of senior officials from the departments of Defense and Energy and the Joint Chiefs of Staff, threw its weight behind the concept in 2005. It authorized a design competition between a New Mexico–based team (with members from Los Alamos and Sandia's Albuquerque division) and a California team (from Lawrence Livermore and Sandia's California division). Of the two preliminary RRW designs, it selected the California one, and Lawrence Livermore was tapped to prepare a final design, called the RRW-1. The RRW-1 warhead is intended to replace the W76, a thermonuclear device carried by submarine-launched ballistic missiles; the last W76s entered the stockpile in 1987. The plan also called for a full-scale engineering design of the new warhead, with initial operational capability by 2012.

From 2004 to 2007, Congress funded the RRW concept but imposed a number of restrictions. It required that the RRW be developed without any nuclear testing and that it lead to a smaller overall stockpile. Congress also mandated that the RRW fulfill only current mission requirements, as defined by the Defense Department, contain improved safety and security attributes, and save money.

But adhering to those restrictions hasn't been enough to guarantee the future of the RRW. For the past two years, Congress has refused to fund it. Meanwhile, the Obama administration has stated that it will not pursue new nuclear weapons. Even so, Defense Secretary Gates has repeatedly voiced his strong support for the program's continuance, most recently in an article in the January/February 2009 issue of *Foreign Affairs*.

WITH A DECISION STILL PENDING, it is worth asking: Is a new nuclear weapon necessary? We think the answer is no.

To understand why, first consider how defects accumulate in a complex system. Most such systems, including nuclear warheads, follow a Weibull curve, also known as a bathtub curve, that characterizes the rate of defects it will suffer over time [see graph, "In the Tub"]. The curve has three distinct parts: 1) a high rate of "birth defects," which gradually decrease over the early period of the system's life; 2) a quiescent, relatively trouble-free period as the system matures; and 3) an "end-of-life" wear-out period marked by a rise in defects, requiring parts to be fixed or replaced frequently. When a system is in its end-of-life phase, the amount of maintenance and repair required to keep it operational becomes burdensome.

In nuclear weapons circles, these defects are referred to as findings, with more serious defects called significant findings, or SFIs. Under Stockpile Stewardship, SFIs are closely monitored. When an SFI is first identified, it is referred to as open; the SFI is considered closed when a solution has been determined, although not necessarily implemented. In general, most findings are due to aging in the nonnuclear part of the warhead and are relatively easily fixed. Some, though, require more involved intervention, including the design and manufacture of replacement components.

The best way to track the aging of warheads is to chart the SFIs over time. The weapons labs do this, of course, and their data show that for the arsenal as a whole, the failure rate is still low. For example, the graph "Old but Okay" shows that only a few age-related SFIs have been reported in nuclear components over time, even in the oldest systems. Other data for 2005 and 2006, the most recent years for which data are publicly available, indicate that the number of new SFIs had declined to the lowest level since the start of the stewardship program. But it's also taking longer to resolve open SFIs; in 2006, it took an average of 70 months to close an SFI, compared to 40 months in 2005.

UNDER WRAPS: The U.S. Stockpile Stewardship Program seeks to maintain a nuclear deterrent without nuclear tests.
PHOTO: PAUL SHAMBROOM

Based on the SFI data, we can draw two hopeful conclusions and one somewhat ambiguous one:

- The Stockpile Stewardship Program is successfully detecting defects.
- The program is effectively addressing them.
- As time goes on, it is taking longer to find a solution to a given defect.

The first two points suggest that stockpile stewardship is doing what it was designed to do. In particular, the number of open SFIs at the end of 2006 was the lowest in 10 years.

The third point, that it's taking longer to close SFIs, has several possible explanations. We can't know for sure which is correct, because the details of the SFIs are classified. It may be that the defects are presenting substantial and growing challenges. Or it may simply be that the labs don't have enough workers, or workers with the right experience, to resolve the problems quickly. In any case, it is not the nature of the defects but the rate at which defects emerge that indicates where a system is on the Weibull curve.

So is the existing stockpile now reaching the end of its Weibull curve? It doesn't look that way to us. Assuming that nuclear weapons age just like any other manufactured system, then as the weapons enter the end-of-life phase you'd expect to see a significant uptick in SFIs. But the data clearly indicate that no such rise is occurring—even in the oldest systems that have already exceeded their design lifetimes. Although there is a spike in the number of SFIs at the 20-year mark, no system older than that has exhibited a trend of increasing SFIs. Indeed, among the five nuclear weapon types in the active stockpile that were at least 25 years old in 2006—the B61-3, B61-4, W76, W78, and W80-1—only one age-related defect in nuclear components was detected. Further, other stockpile data show that SFIs are infrequent even for systems that are more than 30 years old.

Suppose, though, for argument's sake, that the active stockpile is going to reach the end of its Weibull curve in the near future. Even then, that doesn't mean switching to a new warhead is the way to go. For one thing, any new system would also be subject to the Weibull curve; that is, it would experience a significant number of defects during its early years. Proponents of RRW argue that the new designs would be easier to fix and simpler to maintain and pose fewer technical challenges than the warheads they would replace. At this point, there's no way of knowing if those claims are true.

Proceeding with a new nuclear weapon would also likely reduce funds for stockpile stewardship, especially in the current economic climate. Diverting resources from stewardship to the development of a new warhead could lead to a backlog in surveillance, and it could also prolong the time it takes to close SFIs. The result would be diminished confidence in the existing systems.

FOR ALL THESE REASONS, we don't favor switching to a completely new warhead. But there are elements of the RRW approach that may be worth considering and that could be incorporated into the existing program of stewardship. In particular, components that age rapidly could be replaced with newly designed parts that allow increased security and are easier to manufacture. For example, inserting wireless microsensors into or onto these new components would allow in situ monitoring and diagnostics and prevent having to disassemble systems for inspection. Instrumenting every active weapon in this way—rather than just inspecting a relative handful of each weapon type each year—would yield much more useful data about age-related problems.

There are many other options for maintaining the existing arsenal that have yet to be fully explored. One strategy is to reuse more of the components taken from previously tested, disassembled weapons. Another approach is to make more substantial improvements in aging components than is currently done. Of course, any such changes would take time to implement, so it's worthwhile to explore these options now. While the stockpile is undoubtedly aging, it doesn't appear to be close to the end of its useful life. That means there is still time for a careful evaluation of technical options for maintaining the nuclear deterrent, without having to resort to building entirely new warheads. ❑

TO PROBE FURTHER

The JASON January 2007 study of plutonium pit lifetimes is at http://www.fas.org/irp/agency/dod/jason/pit.pdf.

For a discussion of the Weibull curve, see http://www.weibull.com/hotwire/issue21/hottopics21.htm.

More information on the Annual Assessment Reports prepared by the directors of the DOE weapons labs is available at http://www.gao.gov/htext/d07243r.html.

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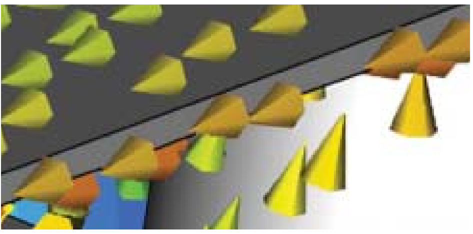

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FIG. 1

Reading a Magazine Article

FIG. 1A

Start with headline

The Death of Business-Method Patents

From now on, you can get a U.S. patent only on a mousetrap—not on the idea of catching mice

FIG. 1B

Enjoy deck

FIG. 1C

Who wrote this?

BY STEVEN J. FRANK

FIG. 1D

Admire large letter 'O'

ON 30 OCTOBER 2008, THE MUCH-MALIGNED "business method" patent died at the hand of the U.S. Court of Appeals for the Federal Circuit, the very court that had given birth to it a decade earlier. The occasion was the case of *In re Bilski*, and although the U.S. Supreme Court has yet to utter the last word, the overwhelming likelihood is that you will no longer be able to patent the newest way of making a buck. If you want to protect new modes of shopping, delivering legal services, reserving a rest room on an airplane, or settling futures contracts, don't ask the U.S. Patent and Trademark Office (PTO) for help.

To critics of the business-method craze, the end could not have come soon enough. They'd complained that the patent system, designed to protect technology, was now spreading like a weed into all areas of life. Patents were being issued for using a laser pointer to tease a cat and for a way of playing on a child's swing. (No joke—the patents were actually issued, in 1995 and 2002.) By covering almost any conceivable activity, the patent system was threatening to crush the very innovation it was meant to foster.

The system's sudden expansion was almost accidental. For nearly a century, in fact, business methods had been expressly excluded. Patents, as the U.S. Supreme Court put it in 1980, were meant for "anything under the sun that is made by man." Made, that is, of stuff—not ideas for doing things not involving stuff. That accorded with European patent guidelines, which provide that "technical character is an essential requirement for patentability of an invention," and with a similar Japanese restriction to technical subject matter.

The original exclusion of business methods from the patent system may have stemmed from a quaint view of technology as something you cooked or cranked. The exclusion was later justified by the notion that free competition was so effective in encouraging new ways to do business that there was no need to add further incentives through the patent system. For decades, business methods stood outside the patent system because no one had made a case for their inclusion.

The problem was that even as the courts perpetuated the ban on business methods, they never really articulated exactly what business methods were. This deficiency irked the Federal Circuit when it decided *State Street Bank & Trust Co. v. Signature Financial Group* in 1998. Faced with a request to invalidate Signature's patent on a data-processing system for calculating the best way to allocate the assets of a mutual fund, the court ultimately decided to let the patent stand. The court's primary concern was whether software and data-processing techniques should be patent-

FIG. 1E *Look at artwork, turn page*

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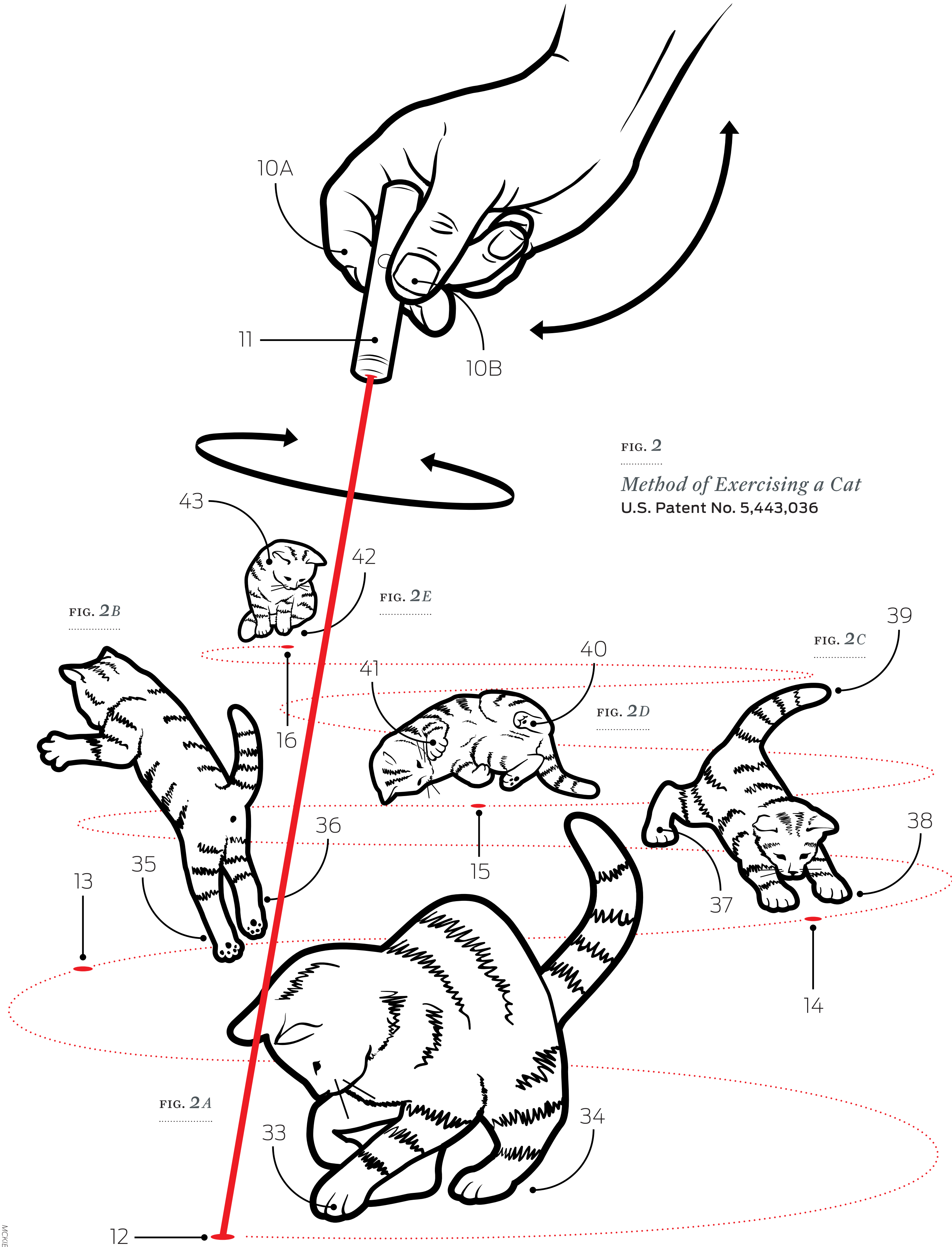

FIG. 2

Method of Exercising a Cat

U.S. Patent No. 5,443,036

MCKIBILLO

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able. Along the way—almost as an afterthought, as we'll see—it threw out the ban on business methods.

The patentability of software was an old and thorny question. The operations of a computer program might be too mathematical, too close to basic laws of nature. Where do you draw the line between math and its application?

In fact, the U.S. Supreme Court had tried three times to draw that line, most recently in the 1981 case of *Diamond v. Diehr*, which involved a patented rubber-curing operation based on a mathematical formula known as the Arrhenius equation. The court upheld the patent, saying that although math can't be patented, an otherwise patentable process doesn't become ineligible simply because it involves math. The Arrhenius equation might be no more patentable than gravity, but everyone agrees you can patent new ways to cure rubber, and their reliance on math shouldn't matter.

The problem is that all software ultimately reduces to mathematical operations, yet only some software controls

That wasn't a bad middle ground, actually, and the Federal Circuit probably didn't really mean to disturb it when it decided, in the *State Street* case, that a mutual-fund management system was patentable. Signature's system was no mere abstraction or equation but rather an obviously useful approach to managing specific business functions. So in its decision, the court welcomed into the patentable fold any "practical application" of an algorithm, formula, or calculation that produces "a useful, concrete and tangible result."

Unfortunately, this test itself is neither concrete nor tangible. What the court probably intended was to broaden patent eligibility beyond software that controls physical stuff, like baking rubber, while precluding patents on computing mere numbers, such as pi or a Fourier transform. But the Federal Circuit thought its new patentability rule eminently clear—so clear, in fact, that it could revoke the ban on business methods. That way, a poorly defined category of exclusion would be eliminated, leaving the lawyers one less term to fight over. The

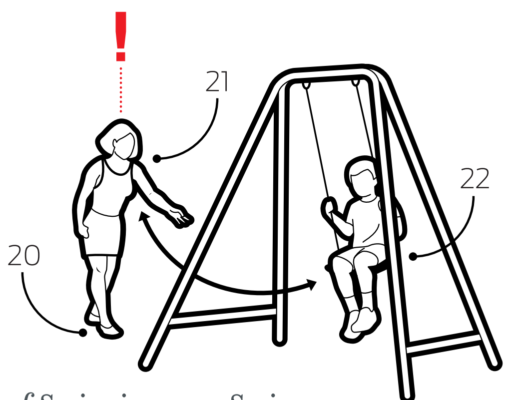


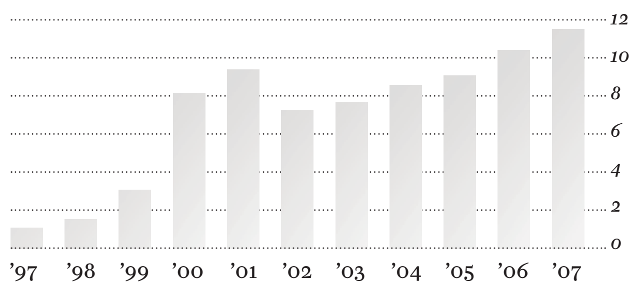
FIG. *3*

Method of Swinging on a Swing

U.S. Patent No. 6,368,227

A Rising Tide

U.S. BUSINESS-METHODS PATENT* FILINGS, THOUSANDS



SOURCE: *United States Patent and Trademark Office* **Class 705 patent*

ILLUSTRATION: MCKIBILLO

actual stuff, like the baking of rubber. If the rest is merely math and therefore unpatentable, does that mean we must deny patents to all software that runs nothing but itself?

BACK IN THE 1990S, COURTS WERE UNCOMFORTABLE going that far. Computers were infiltrating more and more traditional bastions of patent protection—consumer products, telecommunications, medical devices, automobiles—and computer software itself had become a distinct technology industry. It seemed wrong to read *Diamond v. Diehr* so broadly as to deny patent protection to new enterprises, thus leaving the rising tide of software technology outside the system—along with the dreaded business method. So the lower courts found themselves caught between the Supreme Court's antipathy toward excessively mathematical inventions and the proliferating reality of computer software. Searching for a single principle that would exclude equations from patentability without crippling innovation, the courts experimented unsuccessfully with one patentability test after another.

By the mid-1990s, the PTO, attempting to maintain consistent examination practices despite the shifting legal sands, reached an uneasy truce with the courts. The patent office paid lip service to the latest court decisions, but its practice boiled down to rejecting claims that didn't involve technology and demanding more from data-processing applications than simple number juggling.

idea was that every invention would stand or fall on whether it produced something useful, concrete, and tangible.

This approach might have worked, had the PTO and the legal community given a modest scope to those words. But the late 1990s did not favor modesty. The explosion of Web applications and new service models planted the Internet's footprint over vast tracts of unexplored (and unpatented) business territory. Meanwhile, software development was surging, spurred on by plummeting prices for hardware and the proliferation of Web-based distribution channels. Web and software entrepreneurs feared their equally nimble competitors as much as they dreaded discovering their creations in the next version of Microsoft Windows. The rush was on to use the patent system to fend off competition.

Fatefully, the *State Street* court did not declare expressly that patents should be confined to technological subject matter. Perhaps the judges thought it implicit in their concept of "practical utility." The foundations of the patent system, after all, lie in the U.S. Constitution's mandate to "promote the progress of science and useful arts." But because the court failed to articulate what it meant by "practical utility," it removed a key restraint on patenting abstract ideas—such as business methods—without introducing a counterbalance. Maybe you couldn't patent overnight delivery, but what about computing fees based on how far a package travels and when it arrives?

FIG. *4* *Keep reading, not done yet*

The floodgates flew open. Under relentless pressure from patent applicants, and lacking a clear legal basis to keep the door shut against almost anything, the PTO started admitting all comers. Filings for business-related ideas surged fivefold between 1998 and 2000. Actual grants for computer-implemented business patents rose fivefold from 1997 to 2006.

THE PARTY ENDED THIS PAST OCTOBER, WHEN THE Federal Circuit upheld the PTO's decision to deny a patent to Bernard L. Bilski and Rand A. Warsaw for a method of hedging risks in a commodity trading system. The court thus summarily ended its own *State Street* soiree, casting abstractions like legal relationships and marketing schemes into the same dustbin as equations and gravity: You can't patent them. To qualify for a patent, said the court, a process must either transform one kind of stuff into another kind or it must be tied to a "particular machine."

Both options cry out for greater clarity, and the judges did not supply it. And they compounded the ambiguity with an arbitrary distinction, holding that mere numbers can qualify as stuff as long as they represent stuff: X-ray data corresponding to a patient's anatomy, for example, is equivalent for patent purposes to the anatomy itself. Yet all data is ultimately generic: It can just as easily represent something tangible as something abstract. What a byte represents hardly seems relevant to the objective of protecting commercially useful innovation while leaving pure science free to all.

Also, the court did not explain what it meant by a "particular machine." That failure left open the question of whether a general-purpose computer can qualify. If the answer is yes, then in effect, an equation is patentable—as long as you solve it on a computer, which is how most people solve them now.

If that reasoning seems so excessive as to invite pure math back into the world of patents, consider the alternative: If the answer is no—that a general-purpose computer cannot qualify as a particular machine—then *Bilski* has gone far beyond reintroducing a technology requirement into the patent system. Virtually all of commercially useful computer science, including Google's search methods and IBM's techniques for secure data storage, will be ineligible for patent protection (unless they run only on special-purpose hardware). Vast technology industries will now be excluded from the patent system. Either way—with too much math or too little computer science in the patent system—the results are untenable. So the notion of a particular machine only confuses matters.

Unfortunately, what makes sense often gets obscured in the Talmudic dissection of legal principles and the cacophony of competing commercial interests. In the wider debate over patent reform, big industrial incumbents lobby to trim the scope of patents and thereby spare themselves tiresome and expensive lawsuits. Opposing them are pharmaceutical companies and technology upstarts, which rely more heavily on patents and champion the status quo. Each side claims to seek only a level playing field (and to safeguard our children's future, of course). All too rare is the dispassionate, empirical analysis of how well the patent system is performing or of the economic effect of providing patent protection to specific categories of innovation.

In an ideal world, patents would be available only when the social benefits of encouraging innovation through the grant of exclusive rights outweighed the innovation-stifling effects of withholding them. At an estimated average cost of US $1 billion for discovering and developing each new drug treatment, for example, no one would get into the pharmaceutical business without a guarantee of exclusivity.

But that's an impossible standard to implement. No one, and certainly no governmental institution, can reliably assess whether patents help or harm particular forms of innovation. The U.S. Congress often drowns in the conflicting analyses supplied by partisan players, as recent experience with patent reform amply demonstrates. The courts, for their part, aren't supposed to make social policy, which partly explains why they prefer to reason by analogy, deciding what can be patented by comparison to what is or isn't already patentable.

But reasoning by analogy doesn't always work well for new forms of innovation. Software, for example, is on one level just zeroes and ones. Yet it transforms a general-purpose computer into a specialized, task-specific machine. Indeed, a program's very ability to run on any suitable platform means that protecting that program can affect an entire industry.

The upshot is that these endless debates about whether software is more like a patentable machine or an unpatentable abstraction are completely beside the point. What we really need to know, but lack the tools to reliably assess, is whether software patents help or hinder innovation.

FIG. 5 *End begins here*

IF THAT QUESTION IS OBVIOUS TO ASK BUT IMPOSSIBLE to answer, then how are we to decide whether to admit a new candidate into the pantheon of patentable subject matter? Perhaps the best place to begin is where the world's various patent systems tend to agree. One common feature is the focus on what's made (as opposed to merely thought) by man. Other well-established boundaries include the universal unpatentability of laws of nature, physical phenomena, abstract or disembodied ideas, and pure math. Maybe we should exchange lofty expressions of legal principle for practical standards based on these recognized exclusions. Perhaps if patent claims call for hardware and operations that don't reduce to "numbers in–crunch numbers–numbers out," we should consider the subject-matter eligibility bar cleared.

Qualifying as patentable subject matter, after all, is only the first hurdle that any invention must clear. The invention must also be different from past efforts and, critically, sufficiently innovative beyond them to merit the distinction of a patent. This latter requirement of "nonobviousness" is a tough standard, and the courts have been making it tougher. Even the most creative way of teasing your pet or playing on a swing would surely fail to meet this standard today.

Let's also not forget the system's existing capacity for self-correction. Competitors who feel (or fear) a patent's sting can ask the PTO to reconsider its decision to grant the patent, challenge the patent's validity informally or in court, design around it, or pay a license fee. While none of these options may seem attractive to the party on the receiving end, their very existence ensures that most patents ultimately hinder rather than destroy competition. Legislatures will also act when the social costs seem too high, imposing restrictions on patents for surgical procedures, for example.

In fact, if judges conceived of themselves as practical surgeons rather than visionary healers, excising the dangerous outliers with a fine scalpel but otherwise doing no harm, then the system they preside over might well be healthier. ❑

HOLLY LINDEM

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OPEN ARMS

WHAT PROSTHETIC-ARM ENGINEERING IS LEARNING FROM OPEN SOURCE, CROWDSOURCING, AND THE VIDEO-GAME INDUSTRY BY JONATHAN KUNIHOLM

ON THE FIRST DAY of 2005, I was living inside the Haditha hydroelectric dam on the Euphrates River in Iraq, four and a half months into a deployment as the engineer officer for 1st Battalion, 23rd Marines, in northern Anbar province. The night before, I had rustily fingerpicked my way through a bluegrass song on the guitar in the New Year's Eve talent show. I went to bed looking forward to an easy day, a welcome change. I'd been on a long patrol over Christmas—sleeping little, getting shot at. In the morning, I made some of the Starbucks coffee my wife had been sending in her care packages, wrote an e-mail to a friend back home, and headed out to a planning meeting with another officer.

Our meeting was cut short around 9 a.m. when a report came in that one of his riverine boat patrols had been attacked from the shore. I joined the group that went out to respond. We got off the boat and started patrolling the shore on foot, but all we found was evidence of the previous firefight. The Marines began to secure the area.

I was on the ground before I was even aware of the sound of an explosion. The blast from the improvised explosive device—explosives and scrap metal hidden in an olive oil can—broke my M4 carbine in two and nearly severed my right arm. Before the Blackhawk helicopter took me away, I remember telling the executive officer, "I guess my guitar-playing days are over."

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I stayed conscious until we reached the U.S. Navy Alpha Surgical Company at Al Asad Airbase. Then I was anesthetized and sent to the operating room, where I joined the hundreds of amputees who have lost limbs in the two wars we are currently waging.

IMPROVISED EXPLOSIVE devices (IEDs) like the one that got me had become, by mid-2004, our enemies' weapon of choice, and we had spent a lot of time preparing for the threat. We were all to some extent prepared for the possibility of death, but I hadn't given much thought to how my life might change if an IED took one of my limbs. Ever since the first few amputees returned from Afghanistan in 2001, they have been the very public face of modern warfare as it is waged on the ground—a little different from the sterile video output of a laser-guided bomb or unmanned drone. The media coverage often emphasizes the medical care that saves their lives, and the advanced prosthetics they wear, with phrases like *bionic arms* and *thought control*.

THE MOST IMPORTANT THING THAT CAN BE DONE RIGHT NOW TO PUSH PROSTHETICS INTO THE 21ST CENTURY IS TO OPEN THE TECHNOLOGY TO THE WORLD

Lying in a hospital bed in Landstuhl, Germany, I only knew that I had survived and that a young Marine named Brian Parello had not. The doctors had saved my right elbow and part of my forearm. I talked to my wife on the phone. I got a Whopper from the hospital's Burger King. On the way back to the United States, in a morphine haze, I took pictures as we flew over Iceland. I made my first, totally unintelligible attempts to write with my left hand. I already felt worlds away from Anbar province, and I immediately began to feel guilty about the early ticket home, despite its price.

I arrived in the United States on January 5 and was home a week later on convalescent leave. Before I deployed, I was a biomedical engineering graduate student at Duke University, in Durham, N.C., so I did what any engineer would do with the time: I began scouring the Internet for articles on prosthetic technology, trying to envision what my future would look like. My doctor told me I would have to go through a few more surgeries, and once my incisions had healed I would get a state-of-the-art myoelectric arm.

Myoelectric arms have joints powered by electric motors. They are controlled by electrical signals on the surface of the skin, which are produced by the remaining muscles in the arm. According to a 2005 article, the latest and greatest myoelectric prosthetics allowed a wearer to move the limb just by thinking about it. Many articles have anticipated robotic arms that function as well as or better than their human analogues—letting an amputee shave, hold a knife or fork, button a shirt, or turn an ignition key.

I went to see Glen Hostetter, a prosthetist at Duke. I was telling him how excited I was about the arm I would get at Walter Reed Medical Center when he stopped me. "Have you ever seen a myoelectric hand?" he asked quietly.

I had never seen a real one up close. He dug around the back of his office and brought back a demonstration model of a child's myoelectric hand. All I could say was, "That's it?"

Instead of the lifelike motion of individual fingers I had expected, I was looking at a rigid, hand-shaped electric clamp. The creepy "flesh tone" vinyl glove encasing it seemed to be designed more to make other people feel better than to restore function. The arm I eventually got at Walter Reed wasn't much better. The socket offered a limited range of motion. The beautiful cover, painted by an artist, was too fragile for everyday use. The hand couldn't even turn a doorknob, and it was useless for what prosthetists clinically call the "activities of daily living"—the same activities the popular science coverage had talked about. It was not what I expected it to be, nothing like what I'd been promised by the media, and definitely not what I wanted.

THE CHASM between what people think is out there and what is actually available to an amputee has existed for years. The hype isn't limited to the popular press: Scientific research and even scientific literature repeat these claims. The first myoelectric prosthetic arm was demonstrated in 1955. That benchtop presentation included a powered hook that looks remarkably like one I got from Walter Reed. In 1965, a *New York Times* headline proclaimed "New Process Will Help Amputee to Control Limb With Thought." In 2007, a *Popular Science* article described an early prototype robotic hand as "mind controlled" and "dexterous enough to play the piano." There was even a video of the hand playing "Frère Jacques." The headlines have stayed the same, but as I discovered, so has the technology. These prosthetic "concept cars"—even the ones that live up to their claims—have historically had little effect on what most arm amputees actually wear.

Let me be clear: No expense has been spared on providing military arm amputees with the most cutting-edge technology available for replacing their limbs. Amputees at Walter Reed get the works—myoelectric and body-powered prosthetic arms with any attachments we might want, sports and other task-specific arms, cosmetic arms painted with the tattoos we used to have, you name it. In 2006, the Veteran's Administration spent US $1.1 million on prosthetic devices and services. It's the best insurance and the best care in the world, but that doesn't change what there is to buy or what it can do.

The body-powered prosthetic split hook I chose instead of the myo arm has been characterized by some as little more than a rubber band and a stick. But the surprisingly useful mechanical design has endured for close to a century. It has been improved incrementally since 1912, when it was patented by D.W. Dorrance, who lost his arm to an industrial accident. Body-powered prosthetics have cable controls that you move by shrugging and tensing your shoulders, an action that opens and closes a simple hook or hand appendage. After trying everything else, I opted to wear this arm exclusively.

The kind I wear, made by Hosmer Dorrance Corp., is indistinguishable from those worn by amputees after World War II, except in materials: silicones and plastics in the socket, carbon fiber instead of wood or fiberglass in the frame, titanium instead of steel in the hook, Spectra (a type of strong, lightweight synthetic fiber) instead of steel cable for control. Despite two corporate acquisitions, Dorrance's name remains stamped on every hook the company makes.

AFTER IRAQ: Veteran Jonathan Kuniholm [far left], who lost his right arm in an IED attack, opted for the body-powered hook prosthesis, which has changed little since it was patented in 1912. Much the same design was worn by Harold Russell [left], a World War II veteran who became an actor after the war. In the photo, Russell shows why the U.S. Army felt compelled to add a "cigarette notch" to the basic design.

PHOTOS: LEFT, MIKE MCGREGOR; RIGHT, BOB COBURN/ THE KOBAL COLLECTION

The hook retains the rubber grip and "cigarette notch" added by the Army in the 1950s. In fact, you'll find most of the parts of my arm described in a January 1954 article by M.J. Fletcher about the prosthetic state of the art titled "The Upper-Extremity Prosthetics Armamentarium" in the journal *Artificial Limbs*. The same parts and pictures appear in the current Hosmer Dorrance online catalog.

Imagine this pace of development for other everyday products. We would make our calls on big black rotary-dial Ma Bell telephones (lightweight carbon fiber body!), add up to 28 columns of figures using the punch cards of the IBM 650 (improved 56-column design!), and we could go zero to 60 in a Corvette in almost 10 seconds (updated color selection!). If this seems preposterous for other industries, why is it the unfortunate reality of the prosthetic arm industry? Where's Moore's Law for prosthetic arms?

The problem is the size of the market for prosthetic arms, which is just too small to provide any real incentives for innovation. In the modern conflicts in Iraq and Afghanistan, 862 U.S. troops have become amputees, of which only 186 have lost arms as of February 2009. The total arm amputee population in the United States is under 100 000. Anyone who approached a venture capitalist with a business plan with significant technical challenges and only tens of thousands of potential customers would be laughed out of the room. The government is, and will remain, the only game in town as far as research and development in prosthetic arms.

THE SAME year I lost my arm, the Defense Advanced Research Projects Agency (DARPA) began the Revolutionizing Prosthetics program, whose costs now total nearly $100 million. The program was split into two parts: The 2007 project, headed by Dean Kamen's New Hampshire–based Deka Research and Development Corp., was given a two-year deadline to make an advanced prosthetic arm with the world's best existing technologies.

The 2009 program is spearheaded by Johns Hopkins University's Applied Physics Laboratory, in Laurel, Md. APL's goal is to create prosthetics that would, as the hype had it, be "thought controlled." But the team wanted more than control for amputees; they also wanted to restore the ability to feel heat, cold, pressure, and surface texture. I found out about the program at Walter Reed when I was first being fitted for prosthetics, and I was anxious to get on board. Now I'm one of over 300 engineers at over 30 institutions worldwide working on the APL project. At Duke, I'm helping with suspension (attaching the arm to the body), grasping control, and system design.

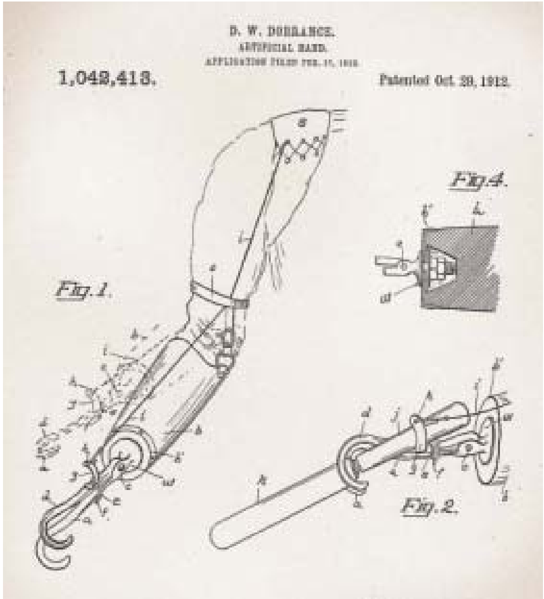
Because of its ambitious goals and compressed schedule, Revolutionizing Prosthetics has often been compared to the Manhattan Project. But let me stress that unlike the Manhattan Project, the entire Revolutionizing Prosthetics program budget could fit inside the cost of a single Joint Strike Fighter—with room to spare.

It's important to talk about the money because, given the scale of the funding and the task, what both DARPA projects have achieved so far is nothing short of incredible. But it's far short of the miracles that have been reported in the press, which have exceeded even the ambitious goals of the entire program.

Remember the *Popular Science* article about the mind-controlled hand that was dexterous enough to play the piano? That article conflated two prototype hands developed by the APL team: the Extrinsic Prototype 2 Hand and the Intrinsic Prototype 2 Hand. The former is powered by one of the most fiendishly complex mechanical devices I've ever seen—it was an early exploration into a possible strategy for controlling individual fingers. The Intrinsic hand was physically capable of all the individual movements necessary to play the piano, but it could not be controlled by a person in real time. There was no muscle twitch or electrical signal being decoded by signal-processing algorithms in real time. The hand was preprogrammed, like a player piano. Dexterous manipulation—the cooperation of two hands and 10 fingers to achieve a complex control goal—is the holy grail of prosthetic hand function, but we're not there yet. The difference between grasp and dexterity is the difference between picking up a Rubik's Cube and solving it.

At this point, no one is even trying to make a hand that will let a user win a Rubik's Cube competition or play the piano. It's just not yet possible to perform tasks that require such dexterity in real time.

Though both DARPA projects come very close to living up to the hype that surrounds them, they must become real products in order to help anyone. We need to push the arm that last mile to the consumer. And that's where we run into the biggest challenge. The most important thing we can do right now to push arm prosthetics into the 21st century is to work around the tiny market size and break down the barriers to innovation.



INNOVATION STAGNATION: D.W. Dorrance patented the Dorrance hook in 1912. His name is still stamped on body-powered prosthetics worn today. *U.S. PATENT AND TRADEMARK OFFICE*

As I discovered the difference between the science fiction and the reality of prosthetic arms, I tried to come up with a solution. I came up with some ideas for simple improvements to the body-powered arms I prefer, but I quickly realized that there wasn't much of a business case for commercialization. So some friends and I started the Open Prosthetics Project in Durham as an online clearinghouse for sharing prosthetic arm designs. The project attacks the most obvious barrier to innovation by giving people a forum in which to share their ideas. We want to start a dialogue among all the stakeholders. We want users and technicians to improve and tweak the technologies they use instead of being stuck with whatever one-size-fits-most device they get (for example, there is a section on our Web site called "Pimp My Arm"). A technically inclined amputee or technician can download our computer-aided design (CAD) files, modify them, and send them to a machinist.

We hoped that we could disrupt the stagnant commercial market, as Linux has for software. We thought openness was the solution. But it turned out not to be that easy.

One major lesson from the Open Prosthetics Project is that sharing a design isn't necessarily enough. Consider the story of the Trautman hook. Edgar Kulcas, a longtime Trautman user, needed a new hook, but it had long since gone out of production. So we improved the old design and made it available on the Internet. You'd think that would mean someone like Kulcas could now simply download the design and have it made by a local machinist. But that's not what happened.

We had the hook made by a rapid prototyper and sent it, along with several others, to prosthetists whose patients, like Kulcas, were eager for replacements. They were "well pleased," as Mr. Kulcas put it, and I'm still getting e-mails requesting these hooks. The problem is that no manufacturer is going to jump up and start making that design again. The long-expired 1925 patent doesn't obviate dubious and expensive trademark claims. Beyond that, many people are nervous about the prospect of manufacturing an FDA-regulated device.

And the future doesn't look much better. Otto Bock HealthCare, one of the largest prosthetics manufacturers in the world, is also the transition partner for the four-year project. That means the company, which is based in Germany, will turn APL's Revolutionizing Prosthetics research into next-generation commercial prosthetics. But Otto Bock is not waiting for the close of the project to use the components the company designed for the first APL prototype arm. Otto Bock plans to use these same components in its next-generation "intelligent arm," which could be on the market as early as 2010. That itself would not be a problem, but in 2008 the company announced that the arm would use a proprietary and encrypted digital communication standard, called the Axon bus, for its new systems. This will create a tectonic shift in the industry. Previously, all companies—be they 800-pound gorillas like Otto Bock or smaller, niche providers like Liberating Technologies, which makes the Boston elbow—used the same mechanical and electrical components originally created by Otto Bock. All the parts spoke the same language. But now the next generation of commercial prosthetics will communicate in a code no one else will be able to crack. Marginal competitors like Liberating Technologies—along with Motion Control, which makes the Utah arm, and Touch Bionics, which makes the iHand—make individual parts that plug into the most widely used systems, the only real spot of innovation in a static landscape. If these companies can no longer make these individual parts without creating an entirely new arm to go with them, they won't survive. That translates into yet another narrowing of options available to amputees.

Otto Bock's decision is not a unique development. Deka Research has declared that it has no intention of participating in any open standard for communication. However, the wrist rotator on Deka's arm remains too large for below-elbow amputees like me to use. Addressing the specific needs of below-elbow amputees was not a DARPA requirement, but most arm amputations are below the elbow. The ability to swap different manufacturers' components would have solved that problem.

It's worth looking at this in terms of the current economic stimulus or recovery packages. We're spending a lot of government money doing something that industry has failed to do, so we need to ensure that we're getting our money's worth. Col. Geoffrey Ling, the program manager on the Revolutionizing Prosthetics project, made it clear from the start that this wouldn't be just another science project—this project would have real benefits in the real world.

So in the middle of the four-year project, the APL team decided to open up the framework of its project. The steps it is taking are virtually unheard of: First, APL is making its virtual environment open source. The APL team has created a virtual integration environment, a training simulation in which signal processing and control techniques can be tested and an amputee can watch him- or herself drive a virtual arm. Second, the team also plans to publish an open control communication architecture for the limb. Finally, APL intends to publish the mechanical interfaces for each physical component, such as the wrist rotator or the finger joints. (Opening the architecture for mechanical and electrical interfaces, by the way, should not be confused with open-source software; adhering to a common interface doesn't require a manufacturer to publish trade secrets about how its improvements were made.)

These innovations will give any company—or individual—access to the physical specifications of the APL arm as well as parts of the control software. They'll even have a virtual environment in which to test their adaptations.

THE BEST way to really move prosthetics research forward is to hitch a ride on a real market. If we can find an application for a myoelectric human interface in the $32 billion worldwide video-game market, for example, we can tap into a massive reserve of people who might not otherwise get involved in the effort. Any tool they develop could be repurposed for prosthetics, allowing that small market to benefit from the economies of scale that are usually available only to much larger ones. The MyOpen project on the Open Prosthetics site is working on ways to create a product that can serve both a niche and a mass market. MyOpen, an open-hardware signal-processing board that will be compatible with APL's arm, will also serve as a universal controller for video games. We want creative people to get their hands on this device and push it to the limits. We want this device to enhance the experience of playing video games, and in doing so, push prosthetics innovation into the 21st century.

Another possible application is robotics. Prosthetic arms aren't the only devices that require centrally controlled powered joints. The compact and powerful motors designed for the APL project—less than a centimeter in diameter and capable of producing 8 watts—could be useful in bomb disposal, hazardous waste inspection, and home-service or hobby robotics, for example. If the communication standards developed for the DARPA project were adopted by one of these industries, then terminal devices like individual joints and hands could see much wider use. In turn, the devices would benefit from much more R&D.

Dean Kamen is famous for founding the FIRST (For Inspiration and Recognition of Science and Technology) mentoring program, which inspires young people to get involved in science and engineering. An open architecture for the Deka arm could be the basis for a FIRST competition with dexterous tasks—think DARPA Grand Challenge or a piano sight-reading competition. I've served as a mentor to FIRST Robotics Team 900 at the North Carolina School of Science and Math. Based on my experience with these students, I think they would relish the opportunity to work on a problem that significantly affects lives.

The greatest revolution of all may be apparent only after the frenzy of prosthetics research spending has evaporated. The design evolution for which DARPA is laying the groundwork could come from any quarter, inside or outside the prosthetics industry. And who knows—someone might even make money doing it. ❑

WHAT HAPPENED TO THE iBOT?

IN CANADA, the national health service will supply a myoelectric prosthesis to anybody who needs one, but in the United States, body-powered prosthetics are more prevalent. That's because myo devices can cost between US $35 000 to $100 000, and the insurance companies are often not likely to pay.

The recent demise of the iBot balancing wheelchair could prove instructive. The $100 million privately funded iBot wheelchair seemed poised to revolutionize mobility for a potential customer base 50 times as large as that for prosthetic arms. The product cost one-tenth of what the DARPA arms will cost, yet faced identical insurance and reimbursement issues. But now Johnson & Johnson has pulled the plug on the iBot after having sold only about 1000 units. Those few users will no longer have access to service or support.

Let's not waste the government's $100 million investment in prosthetic arms on something that will meet the fate of the iBot. *—J.K.*

HOW CAN I HELP OPEN PROSTHETICS?

WHILE IT'S most natural to want to help within your area of expertise, it's not a requirement. We've got challenges like improving the mechanics of a basic body-powered device like the T-Hook or designing the manufacture for one. You can also help with software or circuit-board design for our myoelectric signal processor, the MyOpen. If you're looking for something soothing, you could quarry some mental rocks by filling in the gaps in our patent database. If you're a Web designer or programmer, maybe you'd like to help us redesign our Web site to incorporate the functionality of our multiple Web sites into one, develop the true open collaboration hub that we imagine at Openprosthetics.org, or help me get Google Friend Connect working. These projects are described on our wiki, http://openprosthetics.wikispot.org. You can connect with others on the Open Prosthetics social network at http://openprosthetics.ning.com. That said, the way to help is probably not to call or e-mail me. We figured out early on that my inbox is a choke point. *—J.K.*

AIR GUITAR HERO: The Applied Physics lab will open the architecture for its Virtual Integration Environment, an unprecedented move.

MIKE MCGREGOR

How Green Is My Plug-In?

THE CARBON IMPACT OF THE MILLIONS OF ELECTRIC VEHICLES SOON TO HIT THE ROAD WILL DEPEND ON THE GRIDS THAT SUPPLY THEM

"OUR GOAL IS TO REMOVE THE CAR FROM THE ENVIRONMENTAL DEBATE," SAYS LARRY BURNS, vice president for R&D and strategic planning at General Motors. His vision is that one day cars will emit no harmful pollutants from their tailpipes—or perhaps they'll have no tailpipes at all. And if the beleaguered automaker survives that long, GM may be able to achieve that goal.

BUT NO COMPANY can ever remove cars from the environmental equation. Public impressions are fleeting and malleable, but the laws of physics and chemistry are immutable. Cars require energy to move, and that energy—even if it's stored in a battery pack rather than in fuel sloshing around in a tank—has to come from somewhere.

AND THEREIN LIES the problem. Odds are those batteries won't be recharged with solar or wind energy. In most places, grid power is for many decades going to come from the burning of fossil fuels, which generate their own emissions. So the question becomes: If you power a vehicle with electricity from the grid rather than with fuel from the tank, is that better or worse for the environment, particularly with respect to greenhouse gases like carbon dioxide?

IT'S A QUESTION that dogs not just automakers but also policymakers all over the developed world. Companies and governments are already spending billions of dollars engineering the vehicles and infrastructures to kick off the transition from gasoline and diesel to electricity. Plug-in hybrids even became a mantra during the 2008 U.S. presidential election—with both candidates citing them as an environmental panacea.

BY JOHN VOELCKER

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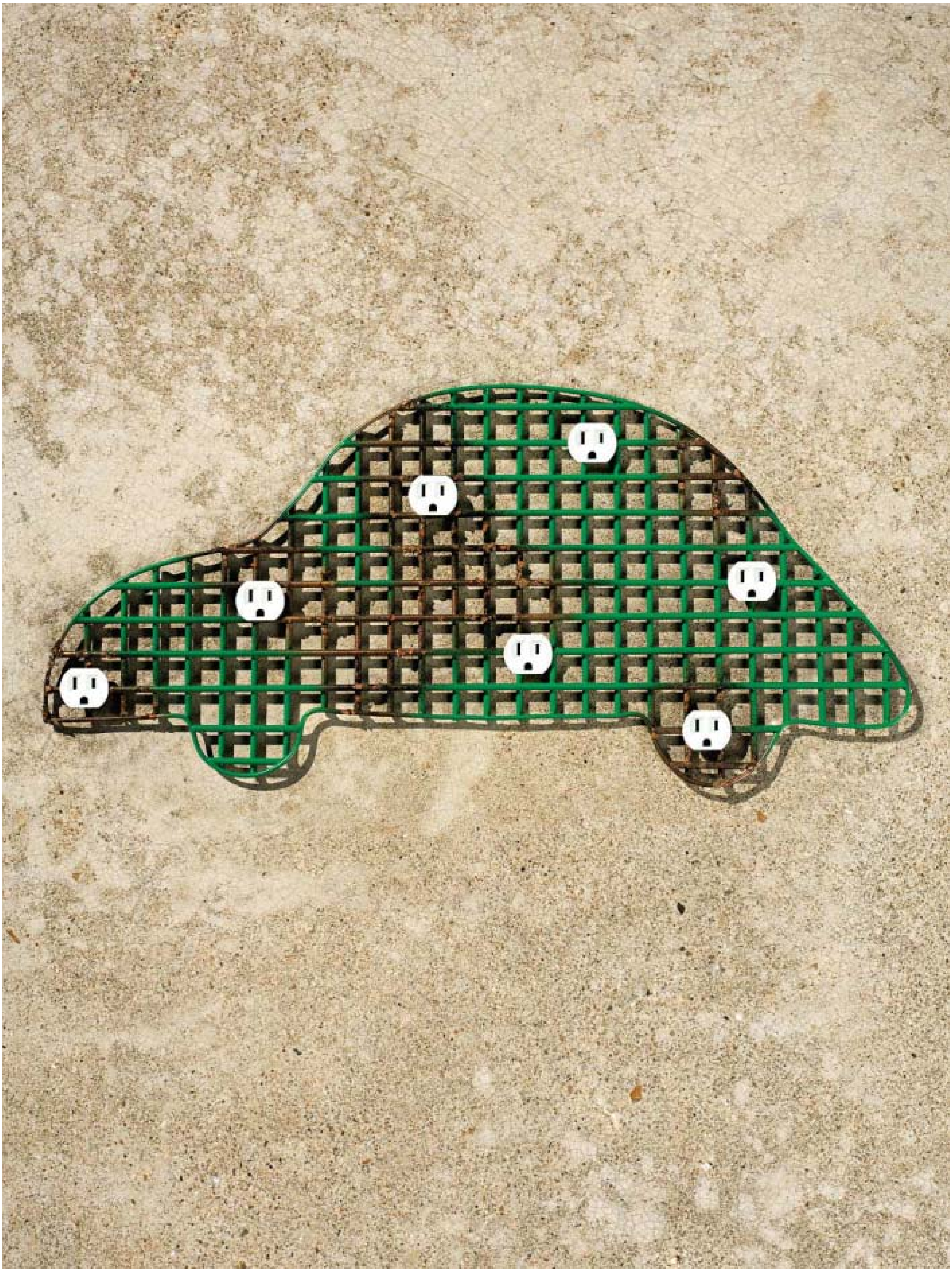


HOLLY LINDEM

A FEW ANALYSTS forecast that by 2020, plug-in vehicles, including plug-in hybrids and purely electric cars, will make up almost a third of new-car sales in the United States. And by 2050, plug-ins could account for most of China's burgeoning vehicular travel. But the environmental implications of such a massive shift are hardly straightforward.

The complexity stems from the multiplicity of vehicles, electricity-generating technologies, and assumptions behind future projections for both. Imagine that two years from now you're comparing a newly available hybrid model that can recharge from wall current with a conventional gasoline car that consumes, say, 9.4 liters per 100 kilometers (25 miles per gallon). In this case, using grid power to drive electrically emits fewer greenhouse gases per kilometer—under any circumstances.

But if you compare the plug-in with an ultraeconomical European diesel or a conventional hybrid-electric like Toyota Motor Corp.'s Prius—either of which burns just 4 to 5 L/100 km—the picture is more complicated: The plug-in emits fewer greenhouse gases in some circumstances, but more in others.

The balance hangs on just what sort of power plants are being used to generate the electricity. So before you decide what to buy, you will need to answer a second question: How green is your grid?

ELECTRIC VEHICLES HAVE been around for decades, although their limited ranges have made them impractical for most people. But now, with automakers preparing to introduce the first vehicles with automotive-quality lithium-ion batteries, the situation is about to change dramatically. Lithium-ion cells can store roughly four times as much energy as lead-acid cells and twice as much as nickel-metal hydride, the kind used in the Toyota Prius and most other currently available hybrid cars.

In the near term, lithium-ion offers the promise of plug-in hybrids that can achieve about 15 to 65 km (10 to 40 miles) of all-electric range, along with purely electric vehicles that can go about 160 km (100 miles) or more before recharging. And as battery costs diminish, the maximum ranges may improve considerably.

The advances in electric drive are unfolding in stages. The Prius, launched in Japan in 1997, was the first mass-production car since the 1930s with an electric traction motor. It has a 1.5-L combustion engine, supplemented by two electric motors and a battery pack, which can provide only short bursts of pure electric travel—1 to 2 km at most. But the Prius can't use grid power to charge its battery: It generates all its own electricity using both engine power and regenerative braking. Having a combination of electric motors and a combustion engine working in parallel is valuable, though, because it allows the Prius (and similar parallel hybrids) to use its fuel much more efficiently.

The next step in modern automotive electrification will be to add grid charging to hybrid-electric vehicles, turning them into plug-in hybrids. Toyota, for example, plans to offer a plug-in version of its Prius in 2010, but it will probably have a limited range in pure-electric mode—up to 20 km (12 miles). Other production vehicles of this sort may go somewhat farther on battery power. (Their quoted electric ranges, however, are not necessarily continuous—at highway speeds or under heavy loads, the engine may switch itself on.)

A further move toward full electrification is the series hybrid. Assuming General Motors is still with us in late 2010, it will begin selling such a car: the Chevrolet Volt, which GM calls an "extended-range electric vehicle." The Volt supplements a 16-kilowatt-hour battery that provides 65 km (40 miles) of pure-electric range with a 1.4-L combustion engine. But as with all series hybrids, the engine isn't mechanically connected to the wheels. Instead, the Volt's engine spins a generator that provides enough current to the battery to sustain its charge and run the car for another 480 km (300 miles) or more on a tank. Even without the engine, the Volt would still function as a limited-range electric car.

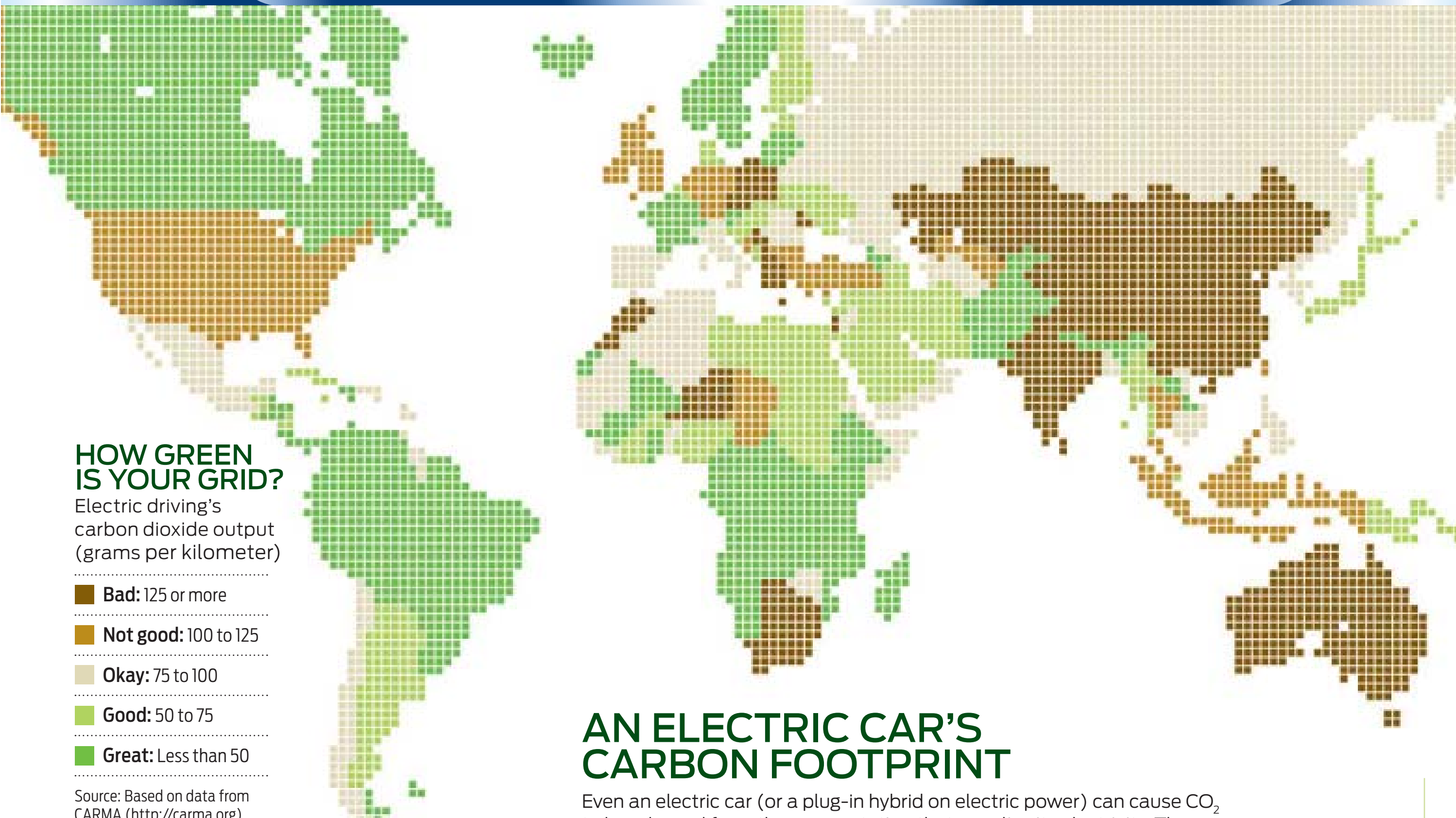
Finally, there are models built as purely electric cars, also known as battery-electric vehicles, whose main drawback at present is the high cost of the battery pack. Analysts expect mass-produced electric cars with reasonably affordable lithium-ion batteries—and consequently with ranges of 160 km or less—to enter the market by 2012. Nissan Motor Co. and its partner Renault have already announced one such compact sedan.

CALCULATING THE GREEN credentials of these different drivetrains is not at all a straightforward exercise. But let's start with the simplest, and for many the most pertinent, yardstick: how much climate-warming carbon dioxide is generated for each kilometer driven—whether it's delivered by gasoline or electricity.

To figure out the amount of CO_2 that might result from running on grid power, the first thing you need to know is how much electricity a plug-in car uses. That, of course, depends on the vehicle in question. Tesla Motors has claimed that its sporty Roadster consumes just 110 watt-hours per kilometer, although some real-world measurements show its usage can be more than twice that—for reasons that may be unique to this specific high-performance car. For something like a plug-in version of a Toyota Prius, a more reasonable number to use might be 150 Wh/km, although more data are needed to know for certain.

The next key factor is how much carbon dioxide is released while the electricity is generated. For that, the U.S. electric grid provides a convenient benchmark. According to the U.S. Department of Energy, roughly 600 grams of CO_2 were emitted for each kilowatt-hour of electricity generated in the United States in 2006. The transmission and distribution of electricity is thought to incur losses of about 9 percent, and charging a car's battery pack is about 90 percent efficient. So the actual amount of carbon dioxide emitted is probably closer to 700 grams—or 0.7 gram for each watt-hour in an electric vehicle's battery pack.

The plug-in's 150 Wh/km therefore translates to 105 grams of CO_2 per kilometer, assuming the car is charged on the U.S.



HOW GREEN IS YOUR GRID?

Electric driving's carbon dioxide output (grams per kilometer)

- **Bad:** 125 or more
- **Not good:** 100 to 125
- **Okay:** 75 to 100
- **Good:** 50 to 75
- **Great:** Less than 50

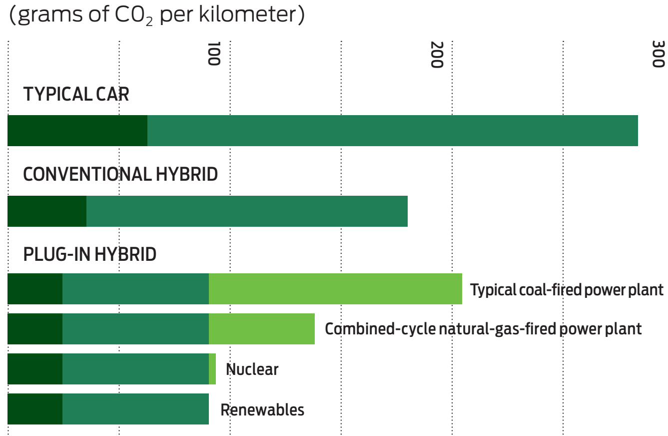
Source: Based on data from CARMA (http://carma.org)

AN ELECTRIC CAR'S CARBON FOOTPRINT

Even an electric car (or a plug-in hybrid on electric power) can cause CO_2 to be released from the power station that supplies its electricity. The results shown above indicate how much, based on each country's average generation mix. In actuality, emissions would vary at a finer scale. The chart below compares overall CO_2 emissions caused by different types of vehicles, assuming that the plug-in travels half its distance on gasoline.

WELL-TO-WHEELS GREENHOUSE-GAS EMISSIONS

(grams of CO_2 per kilometer)



Gasoline: well-to-tank **Gasoline:** tank-to-wheels **Electricity:** well-to-wheels

Source: EPRI-NRDC

power grid, averaged across all its many different generating sources. Remarkably enough, the standard Prius available today emits almost exactly the same amount of CO_2: 104 g/km. And it's possible to go even lower: a few small, ultraefficient European diesels emit less than 100 g/km.

But don't jump to conclusions: The full analysis needs to be done on a "well to wheels" basis. That's because the fuel for the car must be pumped from the ground, transported, refined, and transported again to the filling station—steps that add about a third more CO_2. And you also need to consider how much carbon dioxide would come from plugging a car into your *local* grid, with its particular mix of generating technologies.

THE IMPACT OF electric-drive cars on the grid has been most thoroughly analyzed for the United States, whose citizens buy the most hybrid vehicles. In 2007, the Electric Power Research Institute (EPRI) and an unlikely partner, the Natural Resources Defense Council (NRDC), released the results of an 18-month, two-volume study, aptly titled *Environmental Assessment of Plug-In Hybrid Vehicles*, the first part of which considers greenhouse gases.

The EPRI-NRDC study accounted for many factors, including losses throughout the cycle of fuel production, generation, transmission, and distribution. It also evaluated the consequences of drivers recharging their vehicles at different times of the day. In general, power companies want consumers to charge at night or at other off-peak times to take advantage of unused capacity when demand is lowest, and the companies will be willing to provide strong incentives to make that happen. (Electric carmakers anticipate as much: The Volt, for instance, will allow delayed charging, so a driver can plug in the car when she returns home from work but instruct it not to charge until after cheaper nighttime rates kick in—at 11 p.m., say.)

Finally, the EPRI-NRDC study assumes a gradual rollout of electric-drive vehicles, which only makes sense. It took hybrid cars eight years to surpass 2 percent of the U.S. market, reaching 347 000 vehicles out of 16.2 million sold in 2007. While plug-in hybrids may be adopted slightly faster than conventional hybrids—especially if spurred by tax incentives—the United States *Continued on page 50*

STOP THAT TRAIN

Electronically controlled railway brakes may finally displace a 150-year-old technology

BY ROBB MANDELBAUM

GEORGE WESTINGHOUSE'S many inventions rank him with Thomas A. Edison and Werner von Siemens as founding fathers of our electrified world. Yet, ironically, Westinghouse's first invention, a railroad brake he patented in 1869, was actuated not by electrons but by air. To this day, most railroads rely on that system's principle of releasing air from a pressurized pipe that runs the length of the train and brakes the cars one after the other, at a rate of 152 meters per second.

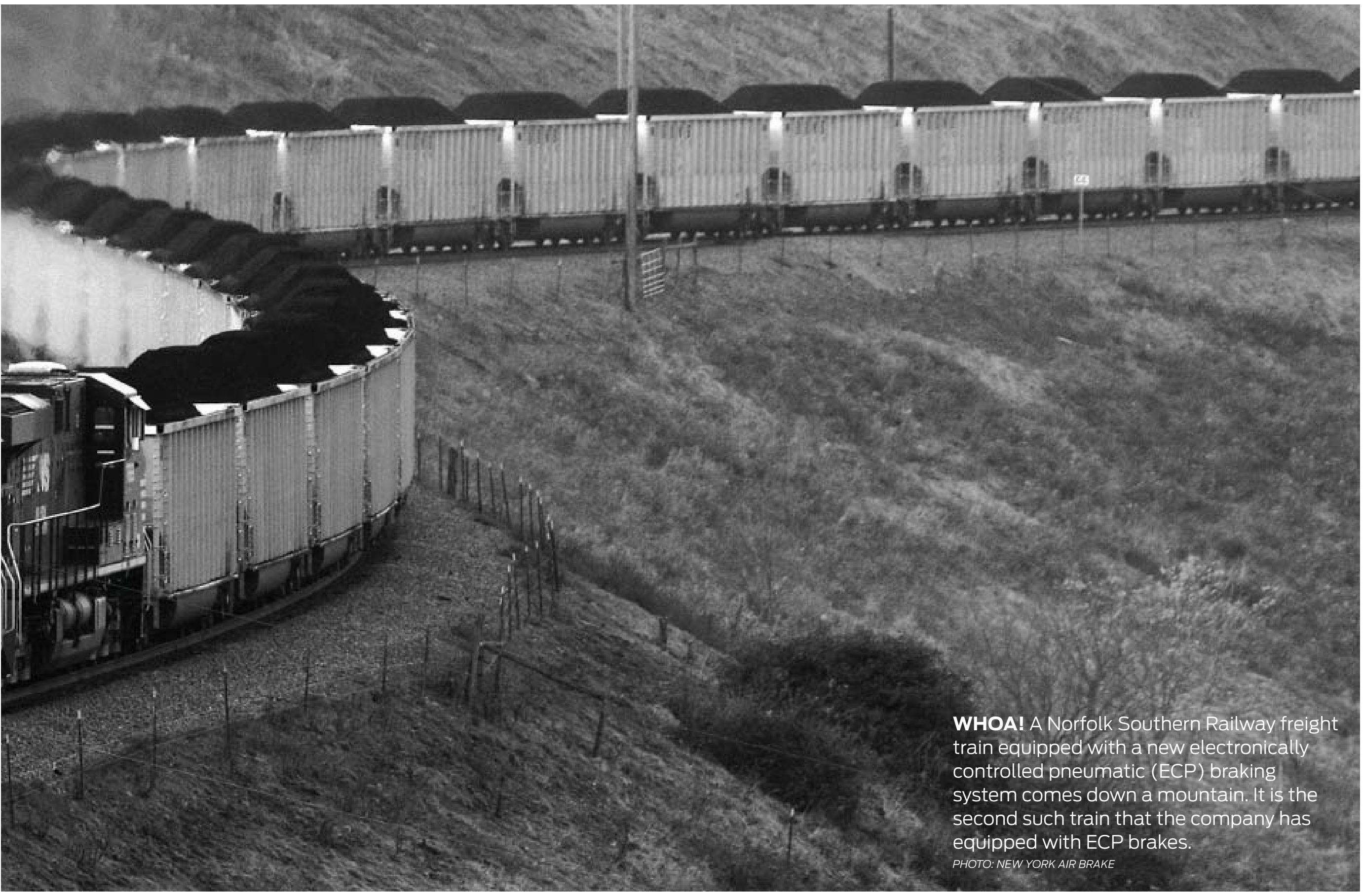
To compound the irony, some of Westinghouse's early competitors proposed electrical mechanisms, but Westinghouse himself rejected these as unreliable. In the past decade, however, the idea has reemerged in a hybrid system that uses an electronic system to control a pneumatic one, so as to set the brakes in all the cars simultaneously. So obvious are the advantages of the new technology—called electronically controlled pneumatic braking, or ECP for short—that its manufacturers are optimistic it will eventually sweep the field.

"We believe that the benefits of ECP will be clearly proven," says Robert Bourg, vice president and general manager of Wabtec Railway Electronics, in Germantown, Md. The parent company, Wabtec Corp., headquartered in Wilmerding, Penn., and the successor to the Westinghouse Air Brake Company, is one of two American companies bringing electronic-pneumatic train brakes to market. The other is New York Air Brake (NYAB), a subsidiary of Germany's Knorr-Bremse, in Munich.

Two major U.S. railroads have recently begun running the first trains equipped with versions of the technology, one using Wabtec's, the other NYAB's. If ECP brakes catch on here, they'll likely appear on heavy-haul railroads around the world, especially in regions that adhere to American Association of Railroads (AAR) standards, including southern Africa, Brazil, Australia, even China.

But will ECP, in fact, catch on? Believe it or not, its ultimate victory is not a foregone conclusion. Standing in the way of implementation are steep up-front investment costs and disagreements over who should shoulder them. Such impediments appear whenever an insurgent technology challenges an incumbent—for example, digital projectors in movie theaters and digital TVs in living rooms. And of course, market forces are not the only actors here. Railroads are heavily regulated—and regulation can make all the difference.

THE WESTINGHOUSE AIR brake, though updated periodically,



WHOA! A Norfolk Southern Railway freight train equipped with a new electronically controlled pneumatic (ECP) braking system comes down a mountain. It is the second such train that the company has equipped with ECP brakes.
PHOTO: NEW YORK AIR BRAKE

retains the basic character it's had since the 1870s, even as trains have grown much longer and heavier. The locomotive forces air into a pipe that runs the length of the train and connects to a triple valve in each car; that valve connects both to the car's auxiliary air tank and to its brake cylinder. The relative pressure of the air in the three devices determines the action.

To activate the brake, the engineer drains air from the pipe, causing a disequilibrium of pressure in the valve that moves a piston, which opens a passage from the reservoir tank to the cylinder; this opening, in turn, allows the air to rush in and set the brake. This is a fail-safe design, because if the train were somehow to break in two, the rupture in the pipe would automatically apply the brakes. To release the brake, the engineer sends air down the pipe once again, which fills each car's reservoir in sequence.

But all this takes time—a 100-car train traveling at 80 kilometers an hour would require at least 1 km to stop. It also takes time to undo the process and get the train moving again.

"We've had long trains where the engineer released the brake and started pulling a little bit too early, while the brakes were still set on the rear of the train," explains Dana Maryott, director of locomotive and air-brake systems at the Burlington Northern Santa Fe (BNSF) Railway. "And coming around a sharp radius, we've literally pulled the train off the track."

Taking a freight train down a long incline is particularly complicated because air brakes cannot be gradually released, the way they are in an automobile, for example. If you try to increase the pressure in the air pipe just a little, the signal will decay after about 600 meters, and it will never reach the brakes in the rear.

To get a feel for the old Westinghouse system, I've come to Bluefield, W.Va., at the eastern end of the Norfolk Southern Railway's Pocahontas Division, 167 km uphill from Roanoke, Va., and another 450 km from the great shipyards of Norfolk and Newport News. Bluefield is America's oldest "hump yard"; it straddles the crest of a low mountain, so that cars unhitched from the locomotive will roll down to switches where they can be shunted onto the desired tracks.

Today, arriving engineers still drape their trains over the crest so that half the train is parked on each side of the hill. "Once you start heading down," says Mike Allran, a senior engineering specialist with Norfolk Southern, "gravity's really going to start pulling on that train good. That's what makes it tough getting off the mountain out here."

Sometime after 1 p.m., Train 762—two long black locomotives pulling 110 shiny aluminum cars, each heaped with over 90 000 kilograms of West Virginia coal—arrives at the Bluefield crest. The train, bound for the power plant at Hyco Lake, N.C., stretches nearly 2 km and weighs nearly 18 million kg. I climb aboard Engine 9191, along with Allran, road foreman Chuck Peters, and engineer Jeff Hayslett, while conductor Norris Kasey takes his brake stick and walks alongside the train setting air retainer valves on 10 cars. The valves reserve about 62 kilopascals of air in each brake

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cylinder, just in case; those cars will be slightly braked all the way to Roanoke. A few minutes later, Hayslett radios his dispatcher and then turns to the rest of us. "Everybody ready to roll?" he asks, and he begins ringing the engine's bell.

Hayslett eases into his throttle to pull us over the hump, but it isn't long before he turns to the brakes. The Norfolk Southern, like most U.S. railroads, teaches engineers to control the train as much as possible with the locomotives' dynamic brakes, which slow the engines by reversing the electric current that powers their traction motors.

In practice, this means Hayslett uses the air brakes to set a base level of braking and the dynamic braking to modulate it. But here the air requires its own precision: If you're short a couple of pounds per square inch, the train might get away. (One pound per square inch is just under 7 kPa.) But if you're a couple of pounds over the mark, the train will stall, and you'll have to fully release the brakes (or "knock off the air") and then set them up again, probably before the reservoirs are fully charged. In the cab it's known as "pissing away your air."

"If you get your train set up the first time right, it means when you go down the mountain you ain't gotta fight the train," Hayslett explains. Otherwise "the train's gonna be working you instead of you working it."

He applies the dynamic brake, and we can feel a great number of gentle bumps as each hopper rolls into the one that preceded it. A few minutes later, with the train bunched up and the speed approaching 21 km/h, Hayslett grips a lever with two hands and reduces the brake pipe air by 8 pounds. His plan is to knock the air off at milepost N350, a flat spot in the grade where he'll have time to recharge the system before setting the brakes up again. Next he'll release the brakes again at Oakvale, W.Va., and then again several miles later, at the start of a very long stretch of flat running.

Eventually, after a long slog up a 16-km hill, we approach the entrance to the Merrimac Tunnel. Burrowing down for 1.5 km, with a grade of just over 1 percent, the tunnel presents an unusual braking challenge. Without braking, the train will gather momentum quickly. But Hayslett can't apply the air brakes while he's in the tunnel.

"Anytime you put the air on, you're subject for something to go wrong," explains Peters. Peters is thinking specifically of what's called a kicker, a sticking valve so sensitive to a reduction in brake-pipe pressure that it begins emergency braking and "kicks" the train swiftly to a halt. Braking miscues like this are called undesired emergencies, and they've grown more irksome for railroads in the last 20 years.

Traveling at 32 km/h, our train could stop in as little as 20 seconds if the brakes were applied at full force, Allran supposes. But then the forces acting on the train might be severe enough to cause it to derail. "You don't want to do that in the tunnel," Allran says. It's a matter of fine judgment, notes Peters, who adds that of the 94 engineers he supervises, "there are three or four I wouldn't want to go down the mountain with."

ANY SYSTEM DEPENDENT on continual human intervention can only be refined so much. In 1991, Dana Maryott and his colleagues at Burlington Northern approached TSM, a small company based in Kansas City, Mo., to develop electronically controlled air brakes. A 65-car coal train, known as a unit train because the cars stay together over many runs, made its debut in October 1993.

Within two years, the line began experimenting with four more such ECP trains. Each car had a manifold that outwardly resembled the old triple valve, but the system took its cues from a portable computer that stored the car's unique ID and some performance characteristics, such as its empty and loaded weights. The car control devices, as they came to be called, were in turn controlled by a computer in the locomotive.

In 1995, the AAR, which was separately investigating alternatives to air brakes, convened a committee of railroaders and brake suppliers to write the standards that would govern the new system's performance and interoperability. They soon faced a fundamental choice: Should the electronic signal to the computer on each car be transmitted by wire or radio?

A wire, like a conventional brake pipe, would need to run uninterrupted the length of the train, meaning that every car would need to be equipped with the new system—a potential logistical quagmire for American railroads, which constantly swap equipment with one another. But a wireless system posed its own problems. Not only would a radio-controlled system require more power (to support the radio in addition to the control circuits), but each car would have to have a power source of its own robust enough to withstand a rugged moving environment. "We looked at axle generators, air generators, and solar power," recalls Bryan McLaughlin, who led the ECP team at New York Air Brake, "and none of that technology was reliable and cost-effective enough to put on the cars."

Ultimately, the AAR did it with cable, choosing a power line transceiver by Echelon Corp., a San Jose, Calif.–based supplier of network control equipment, to thread the signal protocol through the train. The locomotive power supply is 230 volts, based on a 150-car train up to 12 000 feet (3658 meters) long, consuming 10 watts per car.

Additional experiments on other roads followed. But as the AAR team finished its first draft in 1997, a funny thing happened: The railroads started to

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WHERE THE ACTION IS: The locomotive's open compartments [1] reveal the electronically controlled braking system's power supply (white box) and the central control unit (yellow); the red handle in the cab controls the freight car brakes, while the black handle controls the locomotive brakes [2]; and pneumatic and electric cables run from car to car [3]. The microprocessor-based car-control device [4] replaces the old triple-valve system; the cables hang loose at the end of the train [5], and then terminate in a junction box (red panels), which can be opened for cable replacement [6].

NEW YORK AIR BRAKE (6)

lose interest. At first, "they were pretty much all on board. They wanted a new system, not necessarily interchangeable with the old," says Fred Carlson, a retired AAR research engineer who led the team. "And then of course, after we developed it, problems began because it wasn't interchangeable with the old."

You might think interchangeability wouldn't be a problem in the United States, where today seven major carriers handle 90 percent of the industry's business. But there are 560 railway companies in all, operating on short lines and in terminals, and most trains are still strung together and broken apart by turns. In theory, a single incompatible car could thwart an entire train's braking system, and a single stubborn company could foil implementation across the entire network.

An eye-popping price tag for brake conversion compounds the problem. In a 2006 study commissioned by the Federal Railroad Administration (FRA), Booz Allen Hamilton estimated conversion costs at roughly US $40 000 per locomotive and an average of $4000 per freight car; converting the entire North American 2006 fleet would run to about $7.5 billion. (In 2006, the total capital investment of the seven largest railroads was $8.2 billion.)

Who would pay for the transformation, and who would reap the rewards? Hundreds of operating companies own elements of the U.S. freight car fleet, and half the fleet is owned not by railroads but by utilities and giant finance companies that lease them to shippers and railroads. Car owners, complaining that railroads will derive a disproportionate benefit from new technology, want a subsidy of some sort. Railroads, for their part, have a lot of competing needs for scarce capital investment—an AAR report released last year calls for $148 billion over 30 years for "new tracks, signals, bridges, tunnels, terminals, and service facilities."

Saddled with a hard sell in the United States, the ECP manufacturers gamely turned their attention to other markets. In 1998 New York Air Brake outfitted a single train in Quebec's far northeast for Quebec Cartier Mining, which hauls ore on a treacherous route down a mountain 418 km to the St. Lawrence River. Wabtec won a contract to field ECP on a mining train for Spoornet, South Africa's national freight railway company.

LATELY THE FRA has been lauding ECP for the safety advantages it makes possible by keeping the auxiliary reservoirs filled with air so that gradual release can be managed properly. "ECP brakes are to trains what antilock brakes are to automobiles—they provide better control," then-administrator Joseph Boardman declared in August 2006. ECP, he added, "offers a quantum improvement in rail safety." The electronic system reduces the distance needed to stop a train by 40 to 60 percent, and the performance improves as the train grows longer and heavier.

Among the follow-on benefits are reduced travel time, especially when ECP is coupled with other emerging technologies to improve signaling and dispatching; big savings on fuel and on maintenance on car wheels and brake shoes, which together could total at least $575 million a year; and freedom from time-consuming midtrip brake inspections otherwise mandated by the FRA—inspections that delay operations and cost operators about $125 million annually, according to Booz Allen.

These economic incentives are enticing enough to prompt some operators to take a second look—or, in some cases, a third—at ECP. In October 2007, in the Monongahela Valley, Norfolk Southern began operating the first freight train braked exclusively by ECP. The BNSF and the Southern Company, whose flirtation with ECP a decade ago came to grief when they tried to overlay the ECP systems on conventional air brakes, now have retrofitted 260 train cars to use only ECP. Norfolk Southern has upped its order for New York Air Brake ECP systems to equip 600 rather than just 400 cars. Norfolk Southern's vice president, Gerhard Thelen, says that the company will have to replace the majority of its coal fleet—over 20 000 cars—in the next 10 years.

It took roughly a half century for the air brake to become standard equipment, trusted to halt freight trains loaded to the brim. But Cliff Eby, the FRA's former deputy and acting administrator, is confident that the wait for ECP won't be nearly as long. The FRA has already moved to codify inspection waivers granted to BNSF and Norfolk Southern, and it expects to issue general rules by the end of this year.

"We're going to be gathering a lot of data," says Eby, "and if the Booz Allen report [estimating conversion costs] is anywhere close in terms of rates of return and payback period, that data is going to be very persuasive." ❑

TO PROBE FURTHER
An expanded version of this article is available at http://www.spectrum.ieee.org/mar09/trainbraking.

How Green Is My Plug-In?

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has roughly 300 million vehicles on the road, so change to the overall composition of the fleet will be slow.

In practice, this means that in the near future electric cars will impose a very small load on the grid. If projections by GM's Bob Lutz are accurate, some 60 000 new Chevy Volts will hit the road in 2012. In the most optimistic scenario, other makers will add perhaps three times that number. The load of one car being recharged overnight (about 2 kilowatts) is roughly that of four or five plasma TVs. Adding the load of a million plasma TVs to the entire U.S. grid—at 2 a.m.—won't lose utility executives any sleep. Far from it—the prospect of additional demand at precisely the time when they can most easily meet it would make them very happy.

Not surprisingly, the EPRI-NRDC analysis found that plug-in vehicles won't strain the grid. Earlier, less-nuanced studies from Oak Ridge National Laboratory and the Pacific Northwest National Laboratory came to essentially the same conclusions.

As for greenhouse gases, the EPRI-NRDC study determined that total emissions of plug-in hybrids, including the power plants used to charge them, are considerably lower than those of regular gasoline-powered cars—under all scenarios. The comparison between plug-in hybrids and conventional hybrids, however, depends on the sources used to generate the electricity.

Consider a plug-in hybrid that runs half its distance on gasoline and half on electricity derived from an advanced combined-cycle power plant fired by natural gas, for example. Such a car would reduce greenhouse-gas emissions by about 25 percent with respect to the well-to-wheels emissions of a conventional hybrid. Charging that same plug-in using electricity from nuclear power or renewables cuts CO_2 emissions almost in half, because the carbon dioxide emissions involved with nuclear energy (mostly from mining) are minimal and are essentially undetectable for hydroelectric power. But if you run that plug-in with electricity from a typical coal-fired power plant, it now releases from 4 to 11 percent *more* greenhouse gases than a conventional hybrid would.

So how green is your grid—or, more accurately, how carbon intensive is your supply of electricity? In the United States, the three cleanest states—at well below 200 grams of CO_2 per kWh—are Idaho, Washington, and Oregon, due to their extremely high percentage of hydroelectric generation. The worst—at just over 1000 g/kWh—are North Dakota and Wyoming, which use large amounts of coal. California, the state that buys the most Priuses, comes in at roughly 450 g/kWh, about 25 percent better than the U.S. average. Be aware, though, that much electricity crosses state lines.

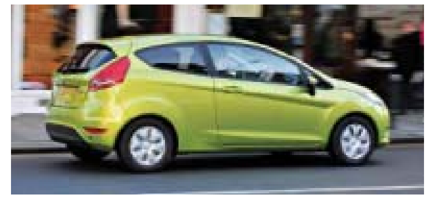
Variation among countries is even more extreme. On the low-carbon end are Norway and Brazil, which get most of their power from hydroelectric stations, or France, where generation is 80 percent nuclear. On the other side of the spectrum is China, where four-fifths of the electricity comes from burning coal—and not at particularly clean plants, either.

THE MORAL OF the story: If you're concerned about the carbon footprint of your vehicle travel, definitely buy a plug-in—*if* you live in Norway, Brazil, France, or other areas with largely carbon-free electricity. Otherwise, have a look at your local grid—and think twice if you live in a place with lots of old coal-fired power plants. For you, a conventional hybrid may be kinder to the planet.

And be prepared to reevaluate that situation each time you trade in, because the grid is bound to change with time—probably for the better. Indeed, the authors of the EPRI-NRDC study excluded a future with large numbers of new coal-fired power plants, viewing that as an unlikely scenario for the United States. Instead, they modeled a gradual shift toward lower-carbon sources of generation.

Declining carbon intensity in the grid, however, will be chased by more and more efficient cars. Fuel economy laws in the United States and China, and carbon penalties in Europe, will make the new vehicles emit less carbon—a trend that is modeled in the EPRI-NRDC study, which supposes that the consumption of gasoline by vehicles of all sizes, including conventional hybrids, will drop by roughly 25 percent by 2050.

LEFT: BYD; RIGHT: FORD



GREEN CHOICES: Countless environmentally conscious car buyers in Europe and North America are looking forward to the day when they can purchase a practical plug-in. The introduction of BYD's newly developed F3DM plug-in hybrid [left] in China suggests that their wait may soon end. But even in its all-electric mode, this car can cause appreciable carbon dioxide emissions at the generating station that supplies its electricity. So driving an ultraeconomical gas or diesel car, such as the Ford Fiesta Econetic [above], may be the better choice in some places.

And that's only reasonable. Already, U.S. and European carmakers are turning to gasoline direct injection, often paired with a turbocharger, to maintain power while reducing engine size. More exotic combustion technologies may be on the horizon, including homogenous charge-compression ignition engines, under development by Mercedes-Benz, General Motors, and others. Eventually, designers may put such advanced combustion engines into hybrid-electric cars, further improving efficiency. Whether these gains could rival the advantages of plug-in vehicles is hard to say. Clearly plug-ins will continue to make environmental sense in nuclear-powered France, but will they ever do so in coal-heavy China?

It's a question worth pondering now, in light of China's determination to nurture its own electric- and hybrid-vehicle industries. The country already manufactures a huge portion of the world's batteries for consumer electronic goods, including the latest lithium-ion cells. And Chinese automaker BYD shocked the industry last November when it introduced the world's first production plug-in hybrid electric vehicle, the F3DM, with a claimed electric range of about 110 km (68 miles). It is being sold only in China and likely wouldn't pass U.S. safety and emissions standards. But

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it may point the way for Chinese automakers—combining the country's strength in battery production with the desire to use vehicle manufacturing as a lever for industrialization, as South Korea and Japan have.

In the long run, the electrification of China's vehicle fleet should be a good thing. But today, plug-in cars in many parts of China may end up releasing more CO_2 than would conventional hybrids—or even the best combustion-powered vehicles. And stiff new taxes on vehicles with low fuel economy will raise the efficiency of all new cars there. Given that, environmental organizations concerned over global warming may want to encourage China to hold off on promoting electric vehicles until the country improves its generating mix.

WHAT DOES IT all mean for planet Earth? Researchers are just now starting to answer that question. Geoffrey Blanford, a senior project manager and global climate policy analyst at EPRI, has taken a first look at what electric-drive vehicles might mean for the world's future.

"Electrification is a big deal," Blanford says. His initial assessment, in the form of an unpublished working paper, suggests that replacing liquid fuels with electricity reduces greenhouse-gas emissions from vehicles and that plug-in hybrid vehicles will become a cost-efficient way to meet carbon constraints.

Blanford came to those conclusions after working with a computer simulation known as MERGE, for Model for Evaluating Regulatory and Global Effects, which calculates the high-level costs and benefits of different energy policies. The late Alan Manne, of Stanford, worked with EPRI's Richard Richels to create the original model to assess policy decisions for different mixes of generating capacity.

Blanford added more detail about passenger vehicles to the model so that he could gauge the global impact of plug-ins specifically. For that he made various assumptions in his working paper about the rate of market penetration for plug-ins from now until 2050, based on projected decreases in the cost premiums for such new technologies as large battery packs and increases in electric-motor efficiency.

The impact of plug-ins was most striking in China, which analysts expect to become the world's largest single automobile market around 2020 and thus a major source of the growth in CO_2 emissions. Blanford showed that electricity could come to power 30 percent of the annual 12 trillion km of passenger-vehicle travel predicted for China by 2050. "It's the scale factor," he says, explaining that because China is starting from such a low number of vehicles, new technology can have a disproportionate impact. "The growth in demand is tremendous," he observes.

Blanford considers the rest of the world, too, and the effect that plug-in hybrids will have on electric-power generation and greenhouse gases. The impact on the grid should be minimal: If one-third of the world's vehicles in 2050 are plug-in hybrids and run half their distance on grid power, the total electricity consumed would be just 3.6 percent of the world's total generating capacity. Even if 80 percent of all plug-in travel is powered by grid electricity, that load would consume only 5.6 percent of capacity by 2050.

"The question of CO_2 impact is subtler," Blanford notes. Even when incremental generation is fired largely by coal, plug-in hybrids produce a modest reduction in overall CO_2 compared with liquid-fueled power, a category that in his study *includes* conventional hybrids. For China, Blanford figures, roughly 4 percent of that country's CO_2 emissions will be prevented in 2050 by the introduction of plug-in hybrids. For the world as a whole, plug-in hybrids would cut annual CO_2 emissions from the use of energy by 3 percent in 2050. If carbon taxes or caps are enacted, plug-ins only get more valuable.

Still, not everybody sees plug-ins as the best bet. Toyota's Jaycie Chitwood and John German, formerly of American Honda Motor Co., among other analysts, suggest that conventional hybrids—with their smaller, less expensive battery packs—will be a lower-cost way to reduce emissions than plug-in hybrids or full-electric vehicles for at least a decade and perhaps much longer. And indeed, the EPRI-NRDC study results suggest that this approach might be just as effective in reducing CO_2 emissions in places with typical coal-fired electrical power generation. In the real world, it's not going to be an either-or choice. Automakers will offer both alternatives, and the market, driven by fuel costs and government incentives, will pick the winners.

Of course, carbon dioxide is hardly the only pollutant to worry about. As with cars, power plants have their own suite of regulated emissions, including some—sulfur and mercury, for example—that aren't an issue for vehicles. So pursuing a policy that reduces one pollutant may end up increasing another. In vehicle travel as in life, there's no free lunch.

IT'S NOTORIOUSLY HARD to predict the energy market. An oil-price decline from US $147 a barrel to $35 in six months would have been thought impossible—until it occurred last year. But assuming the cost of advanced batteries falls over time, electric vehicles seem poised to offer reasons to plug in beyond lower carbon emissions, including smog reduction and energy security for oil-importing nations.

And that's even before the auto marketers get to work. Imagine ads that compare the 10 cents or so it takes to run a car one kilometer on gasoline with the cost of electric cruising—in some markets, 2 cents a kilometer. Then there's the driving experience, a steady, smooth, silent surge of electric acceleration.

Within a decade, no matter what kind of car you're looking for, you'll have the option of an electric or partially electric vehicle. Will you take it? ❑

PURDUE UNIVERSITY

Purdue University Energy Sources and Systems Engineering in the School of Electrical and Computer Engineering

The School of Electrical and Computer Engineering at Purdue University invites applications for a faculty position across the breadth of power engineering at all levels. The Energy Sources and Systems Area of the School currently has four primary-area faculty members and two related-area faculty members with active research programs including: the design, analysis, and simulation of electric machinery, electric drive, and power electronic systems; advanced time-domain simulation techniques; and shipboard, aircraft, and spacecraft power systems.

Outstanding candidates in any area of power engineering will be considered although preference will be given toward candidates with expertise in terrestrial power systems and in emerging areas of power engineering. For all positions, a PhD in power engineering or related field, and a significant demonstrated research record commensurate with the level of the position being applied for are required.

Applications should consist of a cover letter, a CV, a research statement, names and contact information for at least five references, and URLs for three to five papers. Applications should be submitted online at

https://engineering.purdue.edu/Engr/AboutUs/Employment/Applications

Review of applications will begin on 17 December 2008. Inquiries can be sent to ***power_engineering@ecn.purdue.edu***. Applications will be considered as they are received, but for full consideration should arrive by 1 March 2009. Purdue University is an equal opportunity/equal access/affirmative action employer fully committed to achieving a diverse workforce.

CHALMERS

Assistant Professor

in packaging for electronics, MEMS and bioelectronics (Ref: 2008/269)

A research position of Assistant Professor is available in the area of packaging for electronics, MEMS and bioelectronics at Chalmers University of Technology, Göteborg, Sweden. The current research is towards development of nano-materials based technology including metal-polymer nano composite based thermal interface materials, nano-interconnect using carbon nano tubes, nano lead free solders and nanotechnology based conductive adhesives, carbon nano tube based microchannel coolers, 3 D packaging using nanomaterials and processes and nano-scaffolds for stem cell migration, proliferation and differentiation as well as for lap-on-chip applications.

Assistant Professor is a post that offers an opportunity to qualify for higher research positions. The appointment is for two + two years of full-time employment. An assistant professor is expected to reach the Swedish docent level (in Swedish "oavlönad docent" (corresponding to associate professor rank)) within the four years. After two years the progress is assessed. The Assistant Professor is expected to formulate and conduct research including development, synthesis, formulation of new materials and testing of the state of the art materials and processes for electronic, MEMS, bio-electronics and bio-medical applications and to participate in educational activities.

For further information, please contact Prof. Johan Liu, Head of the Bionano Systems Laboratory at MC2, Chalmers University of Technology, phone +46 31 772 3067, ***johan.liu@chalmers*** and send in your application by March 31 2009 online using: ***http://www.chalmers.se/mc2/EN/vacancies***

THE HONG KONG POLYTECHNIC UNIVERSITY
香港理工大學

The Hong Kong Polytechnic University is the largest government-funded tertiary institution in Hong Kong, with a total student headcount of about 28,090, of which 14,260 are full-time students, 10,050 are part-time students, and 3,780 are mixed-mode students. It offers programmes at Doctorate, Master's, Bachelor's degrees and Higher Diploma levels. The University has 27 academic departments and units grouped under six faculties, as well as 2 independent schools and 2 independent research institutes. It has a full-time academic staff strength of around 1,300. The total consolidated expenditure budget of the University is in excess of HK$4 billion per year.

SCHOOL OF DESIGN

Professor / Associate Professor / Assistant Professor in Digital Media

The School of Design, as one of the top design schools in the world, is at the forefront of applying Asian innovation to global opportunities. The School is committed to sustaining excellence in design education, practice, consulting and research; to harnessing the legacy and dynamism of Asian cultures in creating solutions for human needs; and to creating strategic models for products, brands, and systems in local and global markets. The School offers a wide range of programmes at sub-degree, undergraduate and postgraduate levels in areas of Advertising Design, Digital Media, Environment and Interior Design, Industrial and Product Design, Visual Communication Design, Multimedia and Digital Entertainment, Interaction Design, Design Strategies and Practices. Its research and consultancy work are of an applied nature relevant to industrial, commercial and community needs. Please visit the website at http://www.sd.polyu.edu.hk for more information about the School.

The School is now inviting applications for a Professor / Associate Professor / Assistant Professor in Digital Media. The appointee will be in charge of the Multimedia Innovation Centre (MIC) at the School. MIC is an interdisciplinary centre dedicated to research, teaching, training, and outreach activities in the areas of Digital Media, Entertainment Technology, and Video Games. MIC's mission is to advance understanding in the design and development of new products and services in this high-innovation area. Drawing from the Centre's interdisciplinary resources, the appointee will be involved in all aspects of initiating and orchestrating the development of the Centre.

The appointee will be required to (a) oversee the mission, staffing matters and budget of MIC; (b) oversee the Master of Science in Multimedia and Entertainment Technology Programme and develop new programmes as opportunities arise; (c) contribute to teaching at the postgraduate and/or undergraduate levels in the area of Digital Media; (d) network with other institutes and experts to establish important partnerships, share information, and expand research and outreach endeavours; (e) cultivate collaboration with other disciplines, Schools and industry partners to develop new research initiatives; and (f) provide guidance on the application of multimedia technologies and design principles to education, research, and interdisciplinary projects.

Applicants should have (a) a relevant PhD degree plus at least five years' teaching or relevant working experience, OR a relevant master's degree plus at least eight years' teaching or relevant working experience preferably in university administration and leadership experience in the areas of Multimedia, Entertainment Technology, Digital Media Design or related disciplines; (b) a distinguished record of professional, scholarly and/or academic activities and significant background and record in scholarship and publication in Digital Media; (c) qualities of creativity, initiative and leadership; (d) a strong commitment to excellence in teaching, research and professional service.

Applicants with less experience may be considered for appointment at the level of Assistant Professor. The job duty requirements and expectations would be in line with the appointed grade. Applicants should submit a letter of interest and their portfolios including copies of 10 samples of their work in hardcopy, CD or memory stick format with a brief description of the work together with the completed application.

Remuneration and Conditions of Service

Salary offered will be commensurate with qualifications and experience. Initial appointment will be made on a fixed-term gratuity-bearing contract. Re-engagement thereafter is subject to mutual agreement. Remuneration package will be highly competitive. Applicants should state their current and expected salary in the application.

Application

Please submit application form via email to hrstaff@polyu.edu.hk; by fax at (852) 2764 3374; or by mail to **Human Resources Office, 13/F, Li Ka Shing Tower, The Hong Kong Polytechnic University, Hung Hom, Kowloon, Hong Kong.** If you would like to provide a separate curriculum vitae, please still complete the application form which will help speed up the recruitment process. Application forms can be obtained via the above channels or downloaded from http://www.polyu.edu.hk/hro/job.htm. **Recruitment will continue until the position is filled.** Details of the University's Personal Information Collection Statement for recruitment can be found at http://www.polyu.edu.hk/hro/jobpics.htm.

POSITION OPEN Toyota Technological Institute has an opening for a tenured-, or tenure tracked-faculty position in the Department of Advanced Science and Technology. Applications are encouraged from all relevant areas.

Position: Tenured- or tenure tracked-Professor

Research field: Energy engineering (energy generation, conversion, storage, efficient use, etc.) and related opto-/electronic-devices.

Qualifications: A Ph.D. in a relevant field. The successful candidate is expected to demonstrate potential to develop strong and outstanding programs in the above research field. It is also necessary for him/her to supervise students, and to teach advanced and basic courses both at the undergraduate and graduate levels.

Starting date: October 2009, or at the earliest convenience.

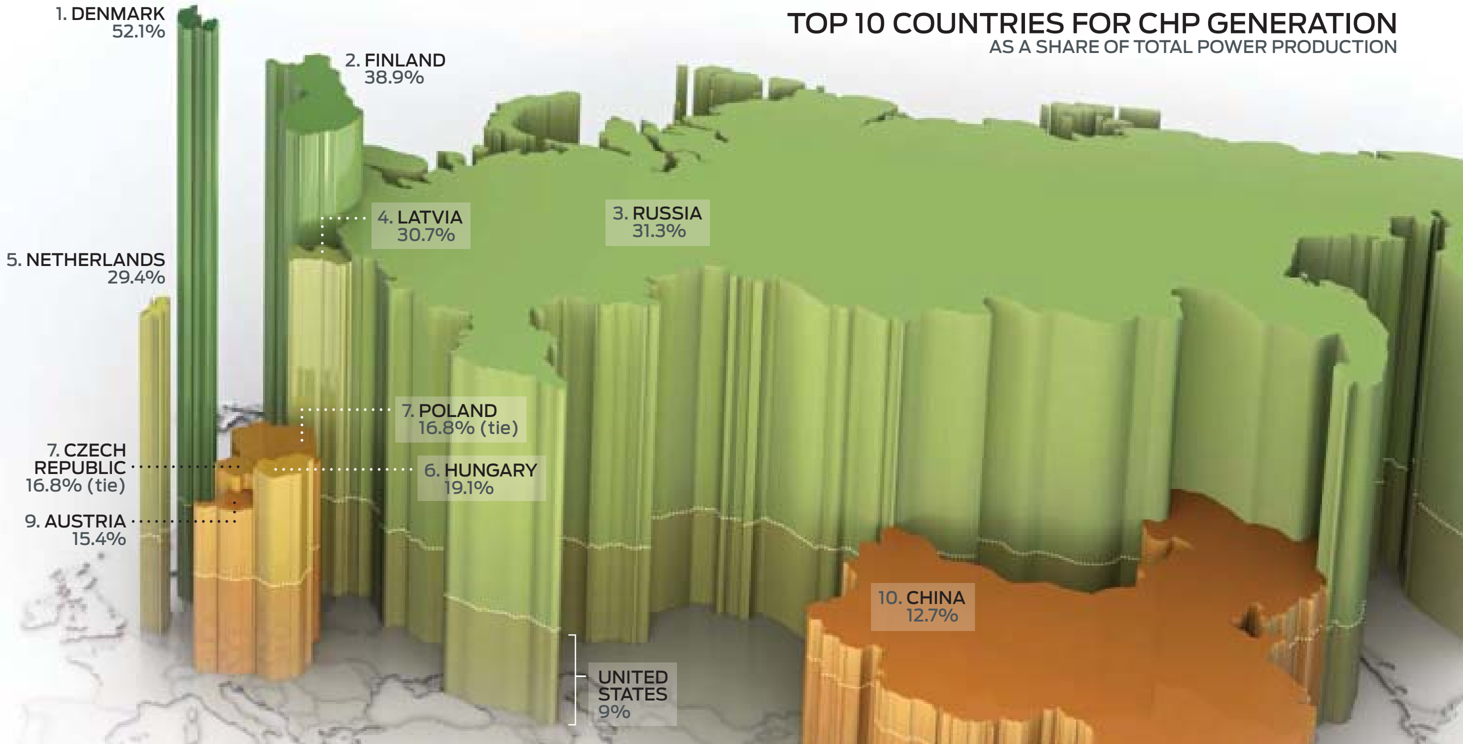
Documents: **(1)** Curriculum vitae (please attach portrait) **(2)** A list of publications **(3)** Copies of 5 selected papers **(4)** Brief description of research activities and future plan for research and education (3 pages) **(5)** Names of two references with Tel/Fax and E-mail address

Deadline: May 31, 2009

Inquiry: Professor Shuji Tanaka, Head of Search Committee (TEL) +81-52-809-1775, (E-mail) tanaka_mat@toyota-ti.ac.jp

The above should be sent to: Mr. Takashi Hirato
Administration Division
Toyota Technological Institute
2-12-1, Hisakata, Tempaku-ku
Nagoya, 468-8511 Japan

(Please be advised to write "Application for Energy Engineering" on envelope)



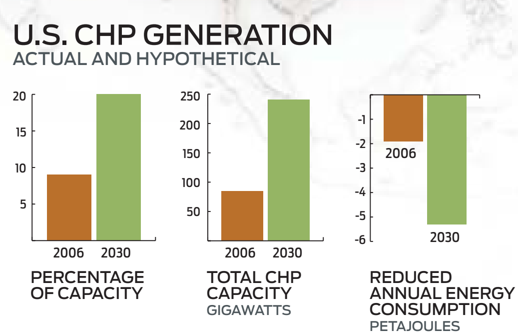
Generation Cogeneration

COAL AND natural-gas power plants lose as waste heat two-thirds of the energy they produce. Combined-heat-and-power (CHP) systems—what used to be called cogeneration—attain 80 percent efficiency by capturing the heat and using it locally. CHP predates electrical grids in many parts of the world.

Tiny Denmark is the world leader, getting more than half its power from CHP. The germ of the plan dates to the early 20th century, when the country installed insulated pipes to shunt heat from big CHP plants to particular city districts to heat homes and water. After the oil crises of the 1970s, the Danes again instituted pro-CHP policies, boosting smaller-scale CHP plants in towns, industries, and individual buildings. Similar measures were taken in other EU countries.

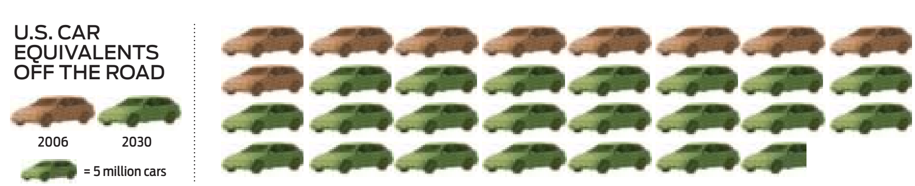
The United States, the boss hog of energy-consuming nations, cogenerates a mere 9 percent of its power, putting it in 13th place internationally. Even so, because of its sheer size, it still has the world's highest installed CHP capacity, at 85 gigawatts. That's enough to save more than 2005 petajoules of fuel and carbon-dioxide emissions equivalent to those of 45 million cars. Oak Ridge National Laboratory recently reported that with the right blend of technology and policy advances, CHP could provide 20 percent of U.S. electricity.

—Prachi Patel-Predd



U.S. TOTAL ANNUAL CO_2 SAVED
MILLION METRIC TONS

248	848
2006	2030



Carbon dioxide savings are based on the Oak Ridge National Laboratory (ORNL) estimate of total CO_2 emissions in 2030 (6851 million metric tons).

SOURCE: "Combined Heat and Power: Effective Energy Solutions for a Sustainable Future," ORNL, 1 December 2008

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