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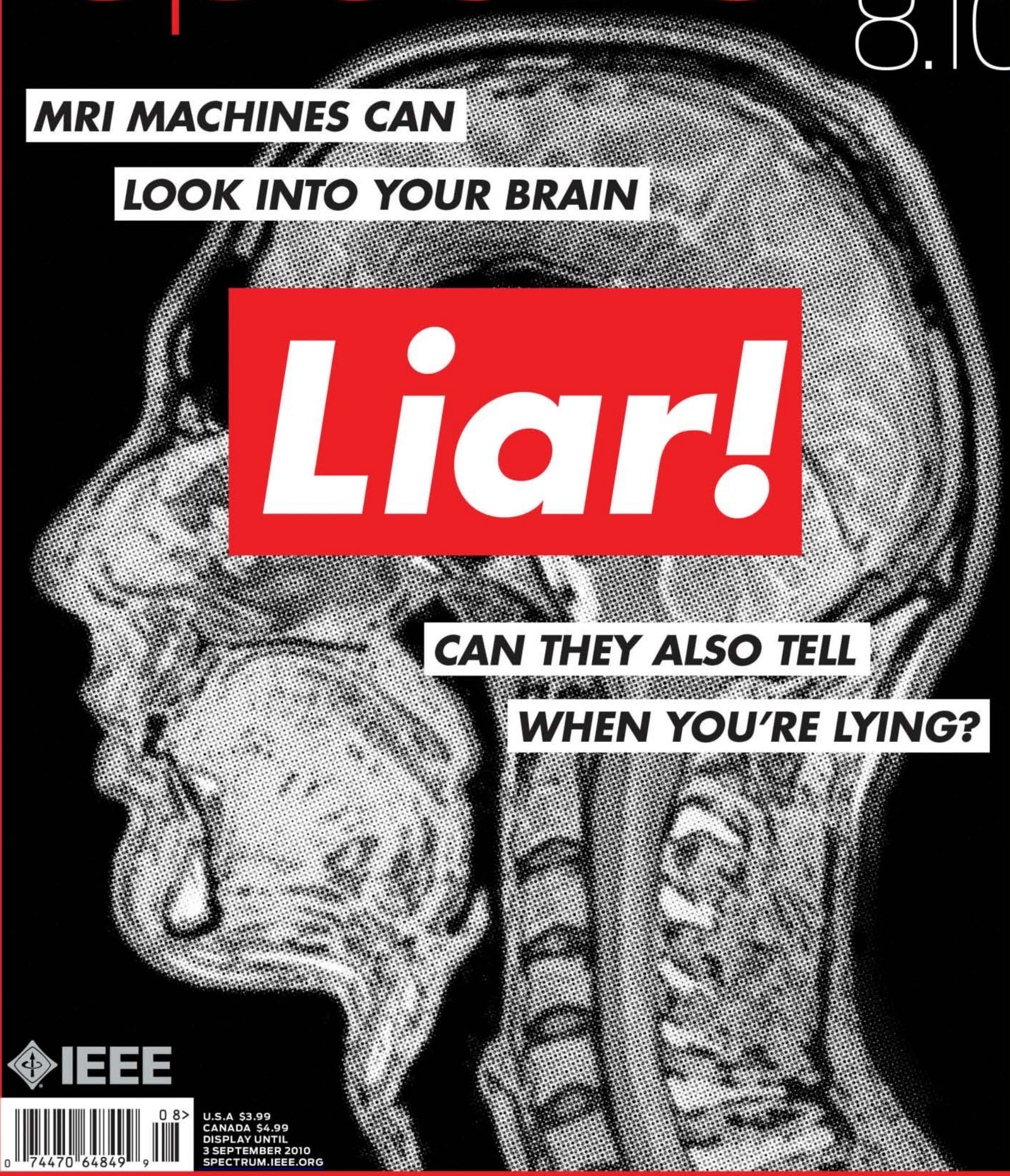

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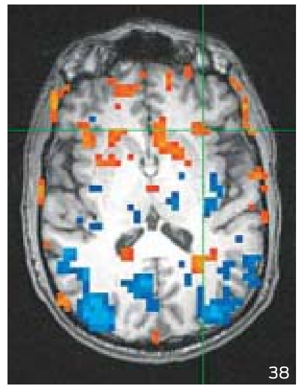




COVER: ISM/ PHOTOTAKE

ABOVE, CLOCKWISE FROM TOP LEFT: ADAM MØRK; NO LIE MRI; BRYAN CHRISTIE DESIGN; VIKTOR KOEN

## COVER STORY



## UPDATE



## OPINION



## DEPARTMENTS





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volume 47 number 8 international

# ieee spectrum 8.10

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The Kindle is not only *not* the only e-book reader in town, it's probably not the best. Or so *IEEE Spectrum*'s staff concluded after a whirlwind three-week test this spring. Fourteen of us vetted the Apple iPad and eight e-readers by doing what editors do best: buying books and reading them—on porches and beaches, subways and buses, sitting up in bed, and lying down on the couch. To find out our favorite, e-read all about it.

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**GLASSES-FREE 3-D**
These days 3-D is everywhere, including TVs, movies, and video games. But those glasses can be annoying and uncomfortable. A team of engineers at National Chiao Tung University, in Taiwan, is working on glasses-free 3-D displays. Read about their work, which was recently featured in the *IEEE Journal of Display Technology.*

**IEEE HONORS CEREMONY**
Get the scoop on the award recipients at this year's IEEE Honors Ceremony, held in June in Montreal. The 2010 Medal of Honor recipient is IEEE Life Fellow Andrew J. Viterbi, cofounder of Qualcomm and developer of the Viterbi algorithm. The event also honored the IEEE student members who are winners in the IEEE Presidents' Change the World Competition.

**INTERNATIONAL BROADCASTING CONVENTION**
This year's conference, to be held from 9 to 14 September, in Amsterdam, will examine the issues arising from the convergence of consumer electronics devices and IP connectivity. Set-top boxes and other receivers, hybrid TVs, LCDs, netbooks, video-game consoles, tablets, and cellphones are also on the agenda.

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# back story

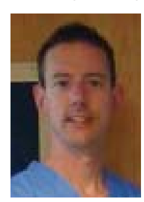
NO LIE MRI (2)

## Reporting From the Field

FREELANCE WRITER Mark Harris was picked up at the San Diego airport and whisked away to a nondescript industrial park just north of the city, where he was ushered into what seemed to be a typical MRI clinic. On the walls of the waiting room hung pictures of brain scans, but his hosts weren't hunting for tumors or aneurysms. They were looking for the truth.

For the past decade, researchers have been investigating the possibility that telling a lie causes telltale activity in certain parts of the brain and that a special type of MRI scan might be capable of detecting the deception. Harris was eager to test that possibility firsthand, and No Lie MRI, one of two companies now providing such services on a commercial basis, offered him the opportunity.

"It was like something out of a science-fiction movie," says Harris, who was eager to discover for himself whether the procedure could really read his mind. But when he looked around and saw the many warning signs about the dangers of mixing metal and the high magnetic fields that MRI scanners generate, he began to have some second thoughts. "I knew I had a mouth full of metal—from eating too many sweets as a kid—and the thought flashed across my mind that maybe the British dentists who had worked on my teeth used a different sort of amalgam, one with a magnetic component." The technician assured him, however, that the MRI machine wouldn't accidentally yank a molar out of his jaw.



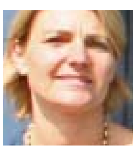
Whether it could pull the truth out of him was a different story, one that Harris tells in his feature article, "Liar!" in this month's issue. ❑

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. 47, no. 8 (INT), August 2010, p. 7, or in *IEEE Spectrum*, Vol. 47, no. 8 (NA), August 2010, p. 9.

# contributors

**MARK ANDERSON** had a 3-D poster of the Fantastic Four superheroes on his wall as a fifth grader, and he's taken an in-depth view of the world ever since. He's now a freelance writer—published in *Wired, Rolling Stone*, NationalGeographic.com—and a regular contributor to *IEEE Spectrum*. Until researching "3-D in the Home" [p. 16], Anderson was perfectly happy with his 11-year-old 27-inch CRT television, but he looks forward to something fancier someday soon.



**ELLEN KATHRINE HANSEN** led the design team for a futuristic green house in Århus, Denmark, named Home for Life ["Home, Smart Home," p. 32]. She drew inspiration from her childhood, which she spent in an even greener place—Lolland, a Danish island known for its sugar beet fields. She left Lolland to attend architecture school at the Royal Danish Academy of Fine Arts, in Copenhagen, where she now lives. Hansen says that when she took her 5-year-old daughter to see the Home for Life, she asked, "Mom, why don't we just live here?"

**CELIA JOHNSON,** who illustrated The Data [p. 52], likes to turn tough concepts into visual vignettes. Not long ago, she was asked to illustrate an article about algorithmic game theory. "It was straight math talk," she says. "I had to read it and reread it, over and over." Finally, she came up with a patchwork of geometric shapes and hands playing rock, paper, scissors. She says her collage style evolved from the predigital days of her career, when she used to arrange magazine spreads for *House & Garden* under giant glass plates.

**KRISHNA M. KAVI,** a professor of computer science at the University of North Texas, got interested in flight data recording after an Egyptian airliner crashed under suspicious circumstances in 1999. Kavi and one of his Ph.D. students, who was Egyptian, decided that the controversy over the crash—and perhaps the crash itself—might have been avoided if flight data had been transmitted to monitors on the ground rather than being archived for later study on the airliner's black box. He describes his proposal for what he terms the "glass box" in "Beyond the Black Box" [p. 44].

**JEONG SUH** illustrated the reactor designs for "Reactors Redux" [p. 23]. When he's not simplifying fuel rods, fission reactions, and other technological concepts with Bryan Christie Design, he likes to "mess around with 3-D renditions of realistic stuff at home." Re-creating the texture of a Porsche or the lighting of a home interior, he says, is a challenge. "You have to catch the little things other people don't see."

**MICK WIGGINS,** who illustrated this month's Technically Speaking column [p. 21], has been a freelance illustrator since 1984 and was one of the pioneers in the transition to digital art. Recently he completed a commission by Penguin Classics to create a series of cover illustrations for the entire John Steinbeck catalog. He received an award from *Communication Arts* for an illustration that appeared in *Spectrum* in February 2009.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CLOCKWISE FROM TOP LEFT: PENNY LEVERITT; KRISHNA KAVI; CHRISTINE CHAN; MICK WIGGINS; DONALD MARTINY; SANDRA UPSON



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# spectral lines

POPPERFOTO/GETTY IMAGES

## Whimsy and Invention

GO INTO any library, said Samuel Johnson, and survey the vanity of human hopes. There you will see a "wall crowded on every side by mighty volumes, the works of laborious meditations and accurate inquiry, now scarcely known but by the catalogue."

Library, shmibrary. For vain hopes, try the files of the patent office.

A laser pointer to divert a cat? A plastic sphere of silence, for tête-à-têtes in noisy bars? A rocket belt, for escaping boring tête-à-têtes? An atomic-powered airplane? A life-expectancy watch? An electric spaghetti-twirling fork? A tiny generator of random noise, to secrete in a friend's office to drive him crazy? An air-bag bodysuit for motorcyclists?

It's easy to poke fun at inventors, but let's not forget the patent lawyers and judges. In June we learned again that lawyers' hopes of defining what can and cannot be patented would still not be satisfied. The U.S. Supreme Court, in a decision awaited all around the world, essentially punted on the key question: the patentability of algorithms and business methods. In ruling on *Bilski v. Kappos*, the court "has thrown up its hands and refused to endorse any one test" of patentability, says Steven J. Frank, who wrote on *Bilski* in our March 2009 issue. We are still no clearer than we were before the decision was handed down.

The more closely you scrutinize the process of invention, the less confident you will be of understanding it. We are told, for instance, that invention typically begins in one person's exasperation over a defect in the standard way of doing things. Oh, really? Then there must be a great deal of exasperation concerning the care and feeding of pets. Look at an airline gift catalog and you'll see dozens of gadgets that appeal to the frequent flier's guilt over neglecting Fluffy or Fido—a pet petter, a doggie umbrella, a timed-release cat feeder, a combination bird trap and cat feeder, a horse diaper.

Whoa, there, horsie. Here we've veered from the ridiculous to the useful. It turns out that miniature horses are particularly good guide animals for the blind—trainable, low-maintenance, long-lived, more dogged than a dog. However, horses can't be toilet trained, and that means they need...diapers. (And toddler-size sneakers, to keep their little hooves from slipping on floors.) Vanity of vanity—yet all is not vanity. Horse diapers make sense.

Again and again this pattern recurs: What begins as a lark develops into a major invention. Remember back when big-iron jockeys dismissed the early personal computers as mere toys? They had a point: The first PCs really *were* toys. Now, though, PCs and their handheld descendants rule the world. Facebook, begun as a way to keep up with members of the opposite sex on the Harvard campus, is now also poised for world domination.

We see the reverse pattern as well, when what begins with serious intent devolves into a form of whimsy. Take the antimissile laser: After decades of work and tens of billions of dollars of government funding, the technology has yet to prove itself on the field of battle. Yet substantial aspects of that technology have found application in protecting backyard barbecues from mosquitoes, as Jordin Kare described in these pages in May. And behind that whimsical invention lies a deeper layer of seriousness, for Kare hopes to use lasers to protect crops from pests. If he does, then he will surely have hammered a sword into a plowshare.

Of course, most inventions, big and little, go nowhere. You have to sift a lot of pebbles to find a grain of gold. That's why the patent law (such as it is) tolerates—indeed, encourages—a playful attitude among the tiny sliver of the population that ever invents anything. Among *IEEE Spectrum*'s readership, of course, that sliver isn't a sliver—it's a goodly slice.

If you have a patent of which you are particularly proud, tell us about it. We promise to take it seriously.

—PHILIP E. ROSS



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# forum


LETTERS do not represent opinions of IEEE. Short, concise letters are preferred. They may be edited for space and clarity. To post your comments online, go to spectrum.ieee.org. Or write to Forum, *IEEE Spectrum*, 3 Park Ave., 17th Floor, New York, NY 10016-5997, U.S.A.; fax, +1 212 419 7570; e-mail, n.hantman@ieee.org.

## WATER VS. WATTS

"The Coming Clash Between Water and Energy" [June] made me wonder: Why aren't we focused on the fast-track building of a fusion-fission hybrid reactor that would produce clean electricity, remove dangerous nuclear waste, and also solve our out-of-control global warming and clean-water problems? My first grandchild was born six months ago, and I want to be able to tell her that we made the right things happen in time to save her future from the unacceptable consequences of climate-change tipping points.

Anthony St. John
*IEEE Life Senior Member*
*Berkeley, Calif.*

Your series of articles on the relationship between our water and electric energy resources are the best I've read anywhere. A key trend and a problem mentioned in many of those articles is the ever-climbing demand for both resources. A solution not mentioned that we have yet to call upon is population control. We'll either impose this solution on ourselves, like the Chinese have, or it will be forced on us by the limited resources of our planet.

Eric L. Holzman
*IEEE Senior Member*
*Baltimore*

Your articles suggest that water and energy are interconvertible, but they are not. You also suggest that water is actually consumed in thermoelectric generators, but it is not. The only process in which water is actually consumed is in the growth of biofuels, in which water is combined with atmospheric carbon dioxide and solar energy to create carbohydrate fuel. A pound of this fuel contains less than a pound of water.

Of course, fresh water is in short supply, but it could be used more efficiently if more investment were made to do so. For example, in power plants, cooling by evaporating water could be replaced with air cooling, but at a substantial investment and operating cost. In agriculture, irrigation water is either sprayed over crops or conducted to the roots via surface streams, and most of it evaporates or soaks down into recoverable groundwater. Water could instead be provided by drip irrigation, an established technology, but also at a cost. Most domestic water goes down the toilet on its way to the sea. Filtered and purified "gray" water is already used for irrigating golf courses and would be perfectly okay for toilets, but again, this would require an investment in both street and household plumbing.

Lawrence Kamm
*San Diego*

*Editor's note:* Throughout the report we used the standard United States Geological Service definition of consumed water: the part of water withdrawn that is evaporated, transpired, incorporated into products or crops, consumed by humans or livestock, or otherwise removed from the immediate water environment. In the case of most thermoelectric power, water is consumed through evaporation in the cooling tower.

## TRANSMITTING LIGHT

"Electrons Unplugged" [May] reminded me of an anecdote from my youth. Before World War II, Germany had a very powerful long-wave broadcast transmitter south of Berlin. Around Berlin in those days there were garden plots where Berliners would escape the city during evenings or on weekends. There were small wooden huts where garden tools and some refreshments were sheltered. Some clever folk discovered that if they pulled a wire over the garden, connected one end of it to a lightbulb, and then connected the other terminal of the bulb to ground, the bulb would light up. Free illumination, in other words! The authorities didn't like that use of radio signals for something other than transmitting information, but it proved difficult for them to stop the practice.

Oskar Sturzinger
*IEEE Life Member*
*Monte Carlo, Monaco*

## CORRECTION

We misspelled the name of the space shuttle *Endeavour* in our March issue ["The End of Blur"], but we will endeavor to prevent such errors from occurring in the future.

# update

more online at spectrum.ieee.org

**DEEP-SEA COMMAND:** From shipboard control rooms, ROV pilots use joysticks to steer robots through deep water and maneuver their plierlike mechanical hands.

*PHOTO: PETTY OFFICER 3RD CLASS PATRICK KELLEY/U.S. COAST GUARD*

## The Gulf Spill's Lessons for Robotics

The demands on the largest underwater robotic armada ever fielded show that ROVs need better automation

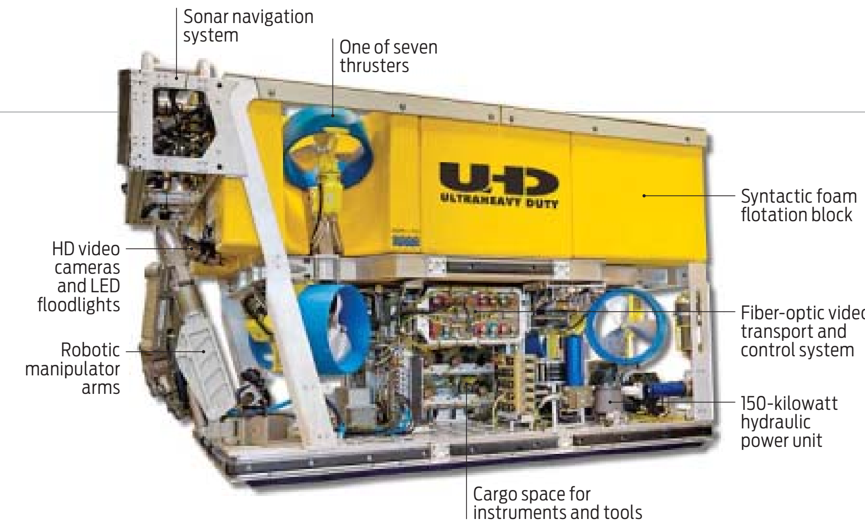
IN THE weeks following the explosion of BP's Deepwater Horizon oil rig on 20 April, a dozen robots the size of moving vans descended into the Gulf of Mexico. Each tethered to a ship by a combination electrical and optical cable, the remotely operated vehicles (ROVs) formed a fleet of unprecedented size.

Deep-water-drilling companies routinely enlist ROVs to maintain and assemble equipment underwater. But in the aftermath of the explosion, BP's attempts to contain the gushing well have pushed these machines to the limits of what they were built to do.

"No one's ever seen anything like this before—that many ROVs simultaneously working on one project," says Tyler Schilling, president and CEO of Schilling Robotics, based in Davis, Calif., which manufactured four of the ROVs in the Gulf and all the robots' manipulator arms. But if predictions about the growth of deep-water drilling prove accurate, big fleets of robots will become the norm, and with that will come the need for much better automation.

Experts mostly agree that the ROVs in the Gulf have carried out their tasks with impressive success, and it is unlikely that better ROVs would have solved the crisis sooner. They have provided the hands and eyes of the entire underwater response operation. For example, when a device inside the rig's blowout preventer failed to automatically seal off the spewing drill pipe, engineers sent ROVs down to jam it into place. When that didn't

# update




**SEAFLOOR WORKHORSE:** Work-class ROVs are designed to do power-intensive work hundreds of meters below the surface. PHOTO: SCHILLING ROBOTICS

work, they sent ROVs to saw off the busted pipe, position a four-story dome over the well, and later install a smaller oil-collecting cap in its place. "In those kinds of water depths, nothing happens without an ROV," Schilling says.

Sending human divers below 200 meters is risky and expensive. BP's gusher sits at 1500 meters—easily reachable by ROVs, which can work at depths as great as 7000 meters when equipped with blocks of syntactic foam. The blocks, made of epoxy and glass microspheres, compose much of the robot's bulk and keep it buoyant.

A "work-class" ROV requires a lot of power to drive its hydraulic pumps, which spin thrusters and animate manipulator arms and tools, allowing the robot to haul half a metric ton. Electricity, at as many as 3600 volts, flows from a generator on board a surface ship to the ROV through its massive tether. Unwieldy and cumbersome beasts, tethers stretch as far as 8 kilometers and weigh up to 15 metric tons, about three times the weight of the ROV itself. "Most of the energy in piloting an ROV goes into moving the cable through the water," says Craig Dawe, chief ROV pilot at the Monterey Bay Aquarium Research Institute (MBARI), in California.

Work-class robots make up less than a third of the world's ROVs, but they are the industry's fastest growing sector. Since shortly after the Arab oil embargo in 1973, the global work-class ROV fleet has grown from just three to more than 700. Texas-based Oceaneering International dominates the market with 253 ROVs and is supplying most of the robots at the spill site in the Gulf. Despite the BP disaster, analysts expect deep-water oil production worldwide to rise from 6 million to 10 million barrels a day within five years. And that will drive the total number of work-class ROVs to 1250 by 2014, according to market analysts at Douglas-Westwood, in Canterbury, England. By then work-class ROV manufacturing and services will be a US $3.2 billion business, says the firm.

Almost all such ROVs serve oil and gas companies. (The remainder maintain subsea telecom cables, aid scientific research, and mine for diamonds.) Most offshore operations need just a few robots for construction and maintenance—laying cables, operating valves, and anchoring equipment, among other tasks.

As companies expand operations with deeper wells and horizontal drilling, "facilities on the seafloor will get more and more populated [with equipment], and more and more complex operations will have to be run," says Julio Guerrero, a mechanical systems and robotics expert at Schlumberger-Doll Research Center, in Cambridge, Mass. "That is what will require development of more sophisticated technology," Guerrero says.

This includes more sophisticated robots. "ROVs will be called on to do more varied tasks and a greater proportion of them," Schilling says. They will likely work in larger numbers and in closer proximity, not unlike the congested operation unfolding around BP's blown-out well in the Gulf of Mexico.

And with so many ROVs working in such close quarters, mishaps are more likely. In early June, two ROVs collided, dislodging a tube inserted into a riser pipe. Later that month, an ROV likely nudged a valve shut on the containment cap that was siphoning oil to the surface. The cap had to be removed for a day and repaired. "There are an unbelievable number of ROVs operating down there," retired Coast Guard Admiral Thad Allen told reporters after the incident. Two setbacks in two months of work "is a pretty good record."

But some ROV experts think this record could be improved. The solution probably won't involve engineering

## GLIDERS IN THE GULF

In early May, after oil in the Gulf of Mexico began lapping at the Louisiana coast, James Bellingham of the Monterey Bay Aquarium Research Institute, in California, sent a flurry of e-mails to colleagues, asking if they could deploy "gliders" to track the spread of the slick. By the fifth week of the disaster, the autonomous, torpedo-shaped submersibles started showing up, sent by Rutgers University, iRobot, and others. The robotic technology, just a decade old, was ready to take on a new challenge.

The gliders move by repeatedly changing their buoyancies, collecting data from the ocean while undulating through it [see "Yellow Submarine," *IEEE Spectrum*, March 2010]. Little by little, they're building a picture of what's happening to the oil—where the currents are carrying it, and how the chemical dispersants applied at the spill site are

YANWU ZHANG/MBARI

**19** Number of thermoelectric power plants in the United States dependent on Gulf of Mexico seawater for cooling, according to the U.S. Energy Information Administration. Plant operators have been watching the oil spill for signs that it could interfere with electricity generation.

new hardware but rather developing more sophisticated software.

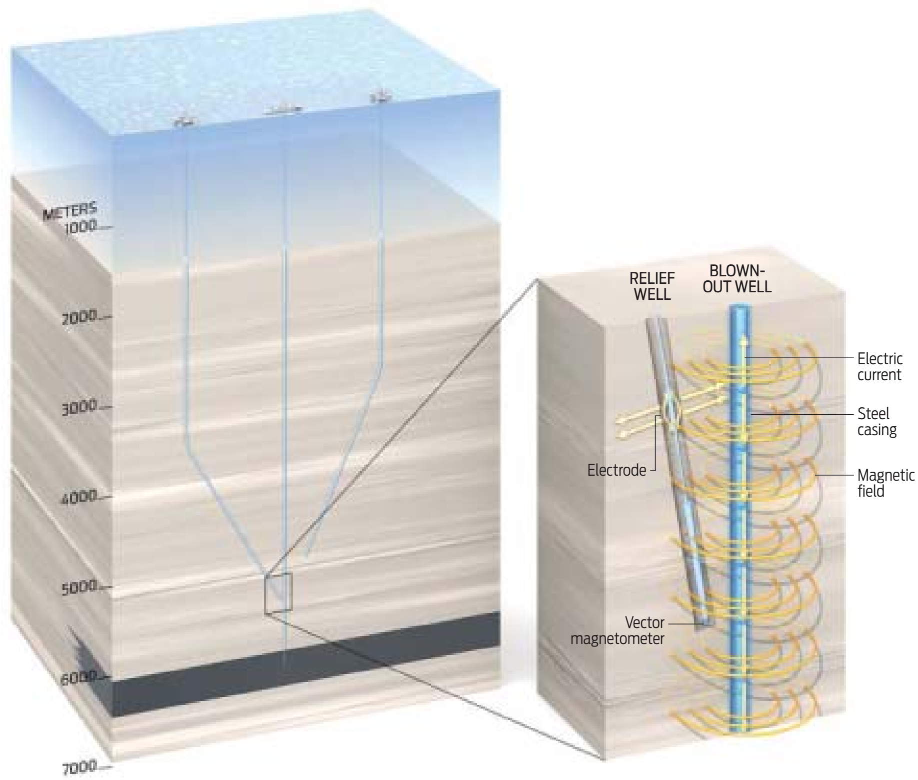
ROVs make mistakes most often because their human pilots do. "Even tightening a nut with a standard combination wrench is really, really challenging for those guys," says MBARI's Dawe. "There's no tactile feedback, no depth perception, no audio feedback of what's going on down there."

To help eliminate human error, ROV manufacturers like Schilling Robotics are developing computer software to automate some of the standard things that ROVs do, like testing a rig's blowout preventer. "Automation techniques will improve not only the time that it takes to do these tasks but also the quality of the results," Schilling says. Most ROVs are already programmed to use pressure and depth gauges, compasses, and Doppler sonar to orient themselves underwater. To minimize costs, Schilling hopes to make the upgraded automation operate using only the cameras and sensors already installed on ROVs.

Automating ROVs could also refine their awareness of what surrounds them, a feature that might have been useful to the robots navigating cables and moving gear in the Gulf, says Andrew Bowen, director of the National Deep Submergence Facility at Woods Hole Oceanographic Institute, in Massachusetts. "It's an incredible ballet they're engaged in down there," he says. —Ariel Bleicher

# Targeted Relief

## Guiding relief wells to end the Gulf blowout requires considerable technical finesse




When it became clear that the blowout preventer on BP's ill-fated well in the Gulf of Mexico could not be activated, BP began drilling two relief wells nearby. These were intended to provide a conduit for injecting dense mud and cement into the out-of-control well, thereby plugging it. At press time, the relief-well operation was scheduled to be completed in early August.

Drilling relief wells in response to a blowout is a standard tactic in the oil and gas industry. But that doesn't mean that such wells are easy to engineer. It takes a rather sophisticated geophysical sensing system, specialized simulation software, and some careful calculations. In particular, guiding the drilling of relief wells is a notoriously tricky business.

The fundamental problem is that a relief well must intersect with the

BRYAN CHRISTIE DESIGN

transforming it. And they're doing it at a much higher resolution than is possible with traditional ocean-observing tools.

"The uses for these vehicles always amaze me," says Clayton Jones, an engineer at Teledyne Webb Research, in Falmouth, Mass., which made 6 of the 10 gliders shipped to the Gulf.

The gliders are packed with sensors that measure currents, temperature, salinity, and water density. They also carry organic-matter-detecting fluorometers, typically used for measuring decaying debris. In the Gulf, oceanographers are testing how useful these sensors really are for finding oil.

And because gliders use very little power to fill and deflate the oil bladders that propel them, they can endure in the sea for up to nine months. "It's like giving a teenager a set of car keys," Jones says. "You never know when he'll come back."

But the gliders almost always check in. Every three hours or so, they pop to the surface and beam their data to satellites and get directions from pilots. The National Oceanic and Atmospheric Administration is using the transmitted glider data to make more accurate predictions about where the oil will go. —A.B.

# update

**An All-Robot Rig** Engineers at Seabed Rig, in Stavanger, Norway, have built a prototype offshore drilling rig run entirely by robots and designed to sit on the seafloor. Automated robotic arms, docked to the rig's power system and directed by remote human operators, would take over tasks normally performed by humans on a drilling platform, such as lowering steel drill pipes. The unmanned Seabed drilling rig would allow companies to drill beneath the ice in Arctic seas, during storms, and with less threat to human safety, its developers say.

*ILLUSTRATION: SEABED RIG*

target well at great depth—almost 4 kilometers below the seafloor in the case of the BP well. "The deeper you are, the more back pressure you can apply," says Elmo Blount, former manager of Mobil's Dallas-based drilling technology group. And it's the back pressure—mostly from the weight of the column of mud injected into the blown-out well—that will stop the flow. But the target is so slender—about 25 centimeters in diameter for BP's well—that hitting it from such a distance is like threading a needle from across the room. With your eyes closed.

The orientation of oil and gas wells is carefully measured as they are drilled, so BP knows where the problematic well is positioned throughout most of its depth. But small uncertainties in the orientation measurements add up. At the depth of the intended intersection point, the location of the well is known only roughly. So the relief well must be very carefully guided to its target as it is being drilled, using some form of geophysical sounding.

In years past, that was done using a magnetometer to detect the steel lining (the casing) of the target well. The problem with that approach is that you have to get pretty close to the casing—within about 10 meters—before you can sense it. The more modern approach has a much longer range and is able to provide the direction to the target well. "I think of it as electromagnetic sensing," BP spokesman Kent Wells told reporters in June. He was referring to a technique developed in the 1980s by Arthur F. Kuckes, who is now an emeritus professor of applied and engineering physics at Cornell University. His system is built and marketed through Vector Magnetics, based in Ithaca, N.Y. The radius of sensitivity with Kuckes's technique is almost 10 times as great as that from the earlier system of passive magnetic sensing.

Representatives of Vector Magnetics declined to be interviewed, but patent filings make it clear that Kuckes's method isn't truly electromagnetic in the usual sense of the word. That is, it doesn't depend on time-varying magnetic fields to induce electrical currents. Rather, the strategy is to inject current into the conductive steel casing of the target well more directly, using electrodes lowered into the relief well. The surrounding rock conducts electricity sufficiently to carry current away from these electrodes, and much of that current is then channeled into the conductive casing of the nearby target well. That concentrated current, in turn, creates a magnetic field whose presence and orientation can be measured several tens of meters away. All you need is an appropriate magnetometer at the bottom of the relief well.

Even with such guidance, drilling a relief well is a slow process. "We're going to drill a couple hundred feet, test and see where we think the well is, drill another 100 to 200 feet, do it again....We're sort of homing in on exactly where the well is," Wells told reporters.

Blount, who helped control blowouts in Sumatra, Canada, and Venezuela using relief wells, emphasizes how much precision is required: "If you hit it at an angle, it'll skid to one side—you're working with inches."

Complicating matters is the requirement that drillers make a good connection between the relief and target wells. Without that, BP might have trouble pumping mud fast enough into the blown-out well to stem the flow of oil and gas. The problem is that the hydrocarbons spewing upward will mix with the mud that is injected, and if there isn't enough mud going in, the density of the mixture will be too low to provide the back pressure needed to stop the flow.

Even if the targeting of the relief well is done perfectly and the connection between the relief and target wells is a good one, there is yet another complication: Too much back pressure could cause the rock formation that surrounds the well to fracture. Then the injected mud would leak into the surrounding rock, and oil and gas would continue to flow up the well. The delicate balancing act comes down to something as seemingly mundane as the density of the mud being pumped. The specialists BP has hired will likely use simulation software called Olga-Well-Kill to determine the optimal mud density and pumping rates. This software was developed at the Institute for Energy Technology, in Norway, after a 1989 blowout at an oil well in the North Sea.

As this article went to press, the outcome of BP's efforts to direct a relief well to its target and the challenges of killing that well afterward were not known. All that was clear was that this ongoing disaster would take considerable technical skill to bring under control.

—David Schneider

**50 femtoseconds** Approximate time it takes a “hot” electron in a solar cell to move from the semiconductor to the electrode. If these hot electrons could be harvested, the efficiency limit of solar cells would double.

# Taiwan Sees Clouds in Its Forecast

## The nation plans to invest hundreds of millions to seed cloud-computing efforts

THINK TAIWAN and you think manufacturing, not services. But the island’s government wants to change that. Taiwan plans to invest NT $24 billion (US $744 million) in the development of cloud-computing technology and services over the next five years. The government predicts that the cloud-computing sector will be worth US $31 billion globally by 2014 and wants its industry to get involved now in order to get a piece of it. Cloud computing uses the Internet and remote servers to store data and run applications for devices such as computers and smartphones.

“We should take advantage of Taiwan’s strong information and communications technology industry, further upgrading it in order to seize business opportunities involving cloud-computing technology,” Premier Den-yih Wu told reporters in June. Officials said that the development of the technology would help push integration among the hardware, software, and service industries, so that eventually Taiwan would be able to export cloud services.

According to Wu’s administration, the government’s five-year investment is expected to be matched by NT $112.7 billion in investments from the private sector, including NT $12.7 billion for R&D. The government estimates the efforts will create 50 000 new jobs.

To speed things along, Wu ordered the establishment of a cabinet-level advisory task force, to help government agencies choose projects to fund and find ways to remove barriers to investment in private sector cloud efforts.

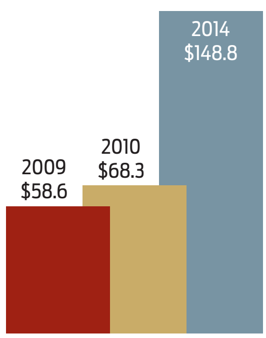
Ming-ji Wu, director general of the Department of Industrial Technology under the Ministry of Economic Affairs, told reporters that the government cash will go to help with supply, demand, and governance of cloud-computing services. On the supply side, it will go toward the integration of cloud-computing systems, data centers, application software, new products, broadband networks, and testing mechanisms. On the demand side, the government is building its own cloud to combine the information systems in over 4000 government agencies nationwide into two or three cloud-computing centers to be located at the country’s science-based industrial parks.

The government push follows some investment by foreign firms. Last November, Microsoft signed a deal with the Taiwanese government to jointly establish a cloud-computing research center. Microsoft inked a separate agreement with Taiwan’s largest phone company, Chunghwa Telecom, allowing the carrier to deploy the Windows Azure operating system for its cloud-technology applications.

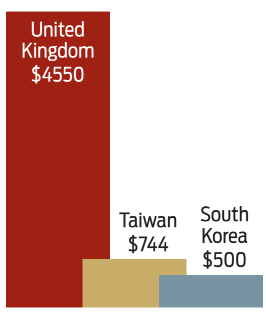
Though its hopes for the cloud-computing initiative are high, Taiwan’s track record with government science and technology programs is spotty. Just weeks after the plan was announced, the Control Yuan, the highest supervisory organ of the central government, censured the National Science Council for poorly designing seven ongoing national science and technology programs. According to the Control Yuan, by the end of 2008, NT $84.15 billion had been invested in those programs, but little of industrial use had been gained.

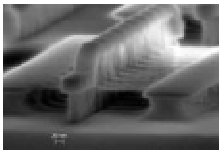
Many other large, cross-agency programs besides those censured by the Control Yuan are also failing, says Chih-cheng Lo, an associate professor of political science at Soochow University in Taipei. “The policymaking process deserves improvement,” he says. —YU-TZU CHIU

**GLOBAL CLOUD SERVICES SPENDING**
US $, BILLIONS
SOURCE: GARTNER




**SOME GOVERNMENT BIG SPENDERS**
US $, MILLIONS



*news brief*

**Slender Circuit**
IBM researchers built the first ring oscillator to be based on silicon nanowires as small as 3 nanometers in diameter. The circuit—a common device for testing the performance of new transistor designs—trumps a breakthrough last year by Samsung engineers, who reported devices with 13-nm-wide nanowires.
IMAGE: IBM

update

# A Dark-Horse Green Laser Shines

New green-laser chips could power HD pico projectors

**COLOR OF MONEY:** Companies are close to green lasers for HD pico projectors . PHOTO: RYANN COOLEY

IF YOU want to show pictures and presentations anywhere, you'll increasingly have the option of buying a mobile phone with a pico projector. And if picture quality tops your wish list, you'll want a model that creates images by mixing the output from red, blue, and green lasers.

The green variant will initially be a cumbersome contraption that combines an infrared laser and a frequency doubler, but researchers at the German electronics company Osram Opto Semiconductors and the Japanese opto-electronics giant Nichia are independently claiming to have met the power and color requirements with a single laser chip. This potential successor to the infrared laser and frequency doubler combo has much to recommend it: It's one-tenth the current size, costs less to make, has a high modulation rate, and produces less speckle, too.

"Picture resolution is given by the modulation capability of the laser," says Osram's Uwe Strauss. "With a diode green laser you have the chance to go up to HD."

Osram won the race to produce the first green chip suitable for a pico projector. In late 2009 it produced a 516-nanometer laser with a continuous 50-milliwatt output, and thanks to further refinement of the device, it reported a slightly greener 524-nm variant this June in the Japanese journal *Applied Physics Express*. According to Osram, the more recent device is almost right in the center of the 515- to 535-nm range needed for a green laser in a pico projector.

But Nichia may have trumped that effort. It has just announced that it will start shipping 50-mW green lasers to customers this August.

Nichia's lasers have a lot going for them. They have an efficiency of 5 percent, a value more than twice that of Osram's and high enough to vanquish the infrared laser and frequency doubler. Typical lifetimes of 10 000 hours may also be long enough to win sales. However, these devices are let down by their emission wavelength, which is only 510 nm.

Among manufacturers it is highly controversial whether 510 nm is truly green or merely blue-green. Nichia insists that 510 nm is green enough for a pico projector, but Osram claims that 515 nm is the minimum.

Osram's success is something of a shock, because it follows a path that was thought to be a technological dead end. When the Japanese tech giant Sumitomo Electric Industries unveiled the world's first truly green laser a year ago, it seemed that a radically different kind of substrate held the key to success in this spectral range [see "Lasers Get the Green Light," *IEEE Spectrum*, March 2010].

Sumitomo's triumph came from growing the laser on an unusual cut of the gallium nitride crystal. Growing a laser on what's known as a semipolar plane created a device that could escape the full brunt of the incredibly strong internal electric fields that naturally occur in these nitrides. These fields are a menace because they impair efficient light generation.

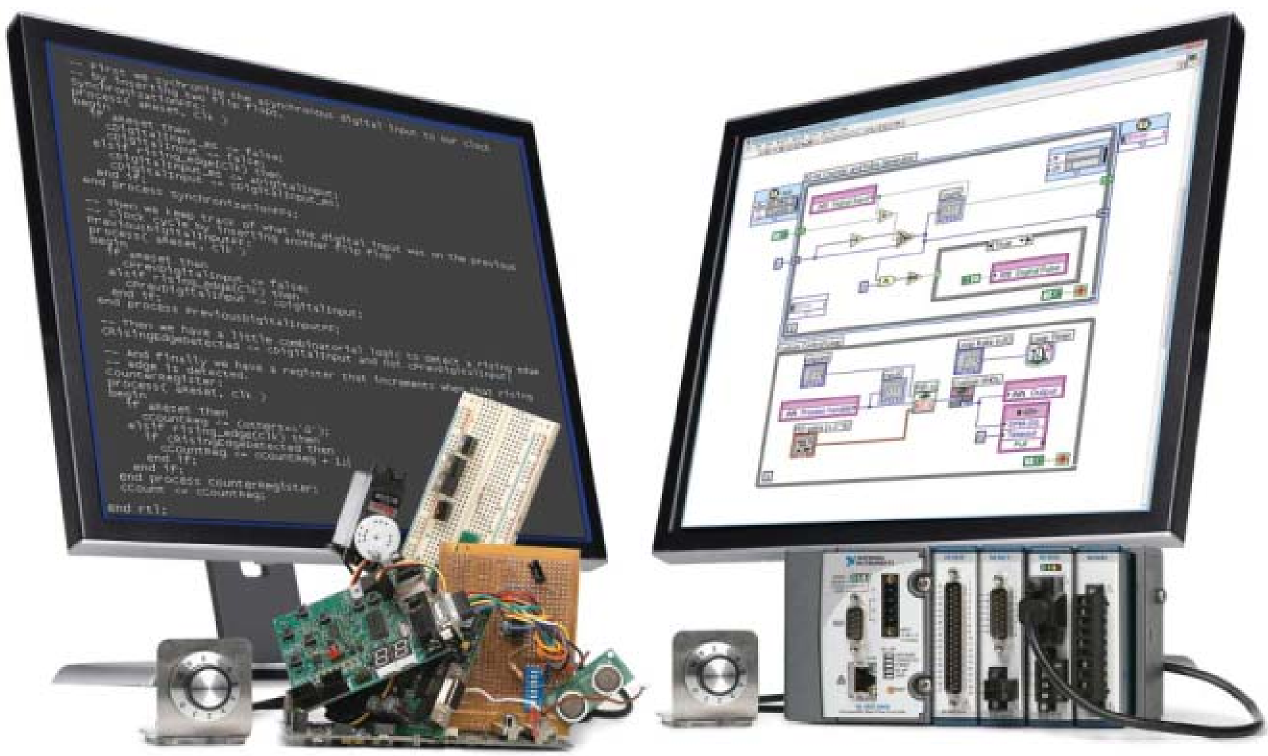
Osram's triumph is surprising because it uses the conventional polar planes that seemed destined for making just violet and blue lasers. The German company has stretched emission into the green by exploiting the sole benefit of internal electric fields—they push output to longer wavelengths. However, you can't capitalize on this unless you carefully engineer the device. Fail to do this and you'd have to crank up the voltage to get lasing. That's no good, because it means you'd have to inject so many electrons and holes into the device that they'd oppose and cancel the internal electric fields you wanted in the first place.

It's hard to tell whether all this effort will reap commercial rewards for Osram. The company has to battle not only Nichia and Sumitomo but also Kaai, in Goleta, Calif., a spin-off cofounded by the inventor of the nitride laser, Shuji Nakamura, that is developing semipolar and nonpolar lasers. Its best results include 525-nm devices delivering 30 mW.

What is clear, however, is that the competition is good news for everyone hankering after high-quality pico projectors.

—RICHARD STEVENSON

# Embedded Prototyping. Simplified.



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# the big picture

**APARTMENT FOR THE APOCALYPSE**

Who will survive an extinction-level event such as a global pandemic, the detonation of multiple nuclear bombs, or the release of chemical or biological weapons? The Vivos Group, based in Del Mar, Calif., is betting that owners of the 20 upscale underground survival shelters it is building across the United States will be among those who remain. Each hardened subterranean resort, designed to house 200 people for a year, will give a new meaning to the term "all-inclusive." Accommodations will include an on-site power generator and water supply, air filters, sewage disposal, a hospital, a library, a gym, and even a jail. The postapocalyptic extended-stay package costs US $50 000 per adult and $25 000 per child.

*ILLUSTRATION: THE VIVOS GROUP*



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SPECIAL REPORT: 3-D AT HOME

tools & toys

# 3-D IN THE HOME

For less than $4000, you can now outfit your living room for 3-D

IN 1954, a few thousand households around the United States—with the equivalent of US $10 000 in today's money to spare—bought the world's first color television sets, from RCA, Westinghouse, and Admiral. Few shows were broadcast in color, and most people wrote it off as an expensive gimmick.

2010 is 1954 all over again, but this time with 3-D. Pricey televisions are showing up in only a handful of homes. Movies in 3-D are doing well at the box office, but none are being broadcast, and many observers are writing off 3-D in the home as an overpriced and overly complicated gimmick. "3-D is a waste of a perfectly good dimension," film critic Roger Ebert wrote in May.

Will the early 3-D adopters get the last laugh, just like the early color TV advocates? A definitive answer would require 4-D glasses to see into the next decade. But between 3-D movies and sports programming—notably the World Cup—and major product investments by the likes of Panasonic, Samsung, and Sony, not just in televisions but also in Blu-ray players, set-top boxes, and other gadgets, it's time to ask the question: What does it take, in time, money, and effort, to put 3-D in your living room?

The answer begins with the glasses.

When you went to see *Avatar*, *Toy Story 3*, or *Alice in Wonderland*, chances are the usher handed you a pair of Polaroid-style "passive" lenses that let vertically polarized light enter the left eye and horizontally polarized light into the right. Or, like RealD's Ray-Ban–like glasses, they used circularly polarized light, in which light waves rotating clockwise pass through the right eyeglass lens while counterclockwise ones pass into the left. Either method results in the illusion of a stereoscopic image onscreen [see sidebar, "Eye Fidelity"].

Passive 3-D is great for theater owners, because the glasses are cheap—in bulk, less than $1 per pair. It's pricier in the home, though, because it puts all the complexity in the TV. As of press time (mid-July), South Korea–based LG Electronics had announced the only passive-display consumer 3-D model—its 47-inch LCD screen LD950.

Every other 3-D television set puts the complexity in the glasses, which turn dark over one eye for 8.3 milliseconds while showing the other eye an image. Then for the next 8.3 ms the glasses darken for the second eye while showing the first eye a complementary image. Together these images make up a stereoscopic picture. As far as the relatively slow human nervous system is concerned, the 16.6-ms interval takes place at the same instant. This happens 60 times per second, and it's how "active" 3-D glasses trick the brain into perceiving stereoscopic depth from a flat screen. At $150 to $200 per pair, these battery-powered, microprocessor-equipped LCD glasses turn out to be one of the more expensive components of the 3-D living room, because you'll need one pair per set of eyes—up to $800 for a classic nuclear family.

PRETTY MUCH any TV on the market today can be made into a 3-D TV, as long as the screen refreshes 240 times per second, which is commonly the case for high-end flat-panel models. According to Brian Markwalter, vice president of research and standards of the Consumer Electronics Association, what puts the 3-D in 3-D TV is an infrared syncing beacon, usually above the screen, that sends out electronic chirps every 8.3 ms, telling the glasses when to darken one lens and lighten the other. Thus the TV sends 120 images per second, but each unique frame gets refreshed twice

**HOME IMPROVEMENT:** A new crop of 3-D–capable TVs, Blu-ray players, and set-top boxes make watching 3-D surprisingly practical. *IMAGE: PANASONIC*

with some video processing to smooth the motion and get rid of the trailing effect that LCDs have had in the past, Markwalter says.

At the moment, unfortunately, no signaling standard exists. That means the glasses you bought for your first-generation Samsung might not work on your friend's first-gen Sony. Markwalter says he's working with manufacturers on a universal standard that they hope to finalize by the end of the year. The hitch is that manufacturers want wiggle room in active eyewear standards. For example, they'd like their TVs to be able to run 2-D video games that can simultaneously show two players completely different scenes from the same 3-D TV panel. This complicates the standardization process for Markwalter and his committee. And, as ever, it makes video games a story unto themselves [see "3-D Video Games" at the end of this section].

In the world of noninteractive content, fortunately, the dust has all but settled. In December, the Blu-ray Disc Association released specs for full 1080p HD 3-D Blu-ray discs, which existing late-model Blu-ray players, such as the Sony BDP-S470, will support with a free firmware upgrade. (New 3-D Blu-ray players, such as Samsung's BD-C6900XAA or Panasonic's DMP-BDT350, support the 3-D standard out of the box.) That will give Blu-ray a leg up on cable and satellite set-top boxes, which will also be delivering 3-D to the home but not in full high-definition.

So for instance, in June DirecTV began offering a free upgrade to its receivers that horizontally squeezes each frame to fit more information—a little like CinemaScope did for wide-screen movies in the 1950s and '60s. A full HD frame is 1920 pixels wide by 1080 pixels high. But with 3-D, the left and right eye each gets its own dedicated frame. So DirecTV's "side-by-side 3-D" broadcast protocol displays first a lower-resolution frame for the left eye (at 960 by 1080) and then a lower-resolution frame for the right eye. Markwalter said that widespread full HD 3-D cable and satellite broadcasts (that is, 1920 by 1080 to both eyes, as 3-D Blu-ray offers now) is still years off.

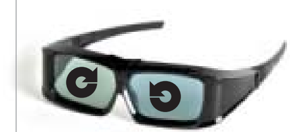
THE ULTIMATE dominance of 3-D in the marketplace seems assured. Scott Steinberg, head of the Seattle-based technology consulting firm TechSavvy Global, says, "The question is the speed of adoption. I can guarantee you that manufacturers are way more bullish than actual end users themselves." Marquee 3-D movies like *Avatar* or *Toy Story 3* on Blu-ray may draw curious onlookers to the Best Buy showroom floor to check out 3-D TV setups. But Steinberg doesn't think consumers will make big purchase decisions based on a limited library of 3-D feature films alone. His best guess at widespread adoption: five to seven years hence.

Sports will be the biggest 3-D TV selling point in the coming year, Steinberg says. In addition to the World Cup, golf's Masters Tournament was broadcast in 3-D in April, as was baseball's All-Star Game in July. ESPN's newly launched 3-D channel, promising at least 80 events in its first year, could draw nongeeks into the 3-D net. "Sporting events were the killer app for high-definition television," says Steinberg. "I have no reason to doubt that it wouldn't be the same for 3-D TV." Still, he wonders if enough HD buyers will still feel enough techno-lust to go on a 3-D spending spree. "Customers are being asked to make a second leap of faith in the middle of one of the worst economic crises in history," he says.

To be sure, the switch to 3-D isn't all-or-nothing. Shawn DuBravac, chief economist of the Consumer Electronics Association, says a 3-D TV setup is ultimately still just a nice HD screen with some fancy glasses. As the marginal cost between HD and 3-D drops, he says, 3-D will become just another add-on in any home theater system.

"The key with 3-D is it's largely a feature," DuBravac says. "If somebody doesn't want to use it, they don't have to. But the option is there for them."

—MARK ANDERSON



**Eye Fidelity**
The right eye receives only light waves rotating clockwise, and the left eye gets them counterclockwise.
*PHOTO: XPAND*

**Polarized Coordinates**
The liquid-crystal filter in front of the projector lens switches states 144 times per second—letting through only circular clockwise-polarized light, then counter-clockwise, then clockwise, and so on. The filter is synced with the projector so that the image for the right eye is projected when the filter lets through clockwise-polarized light; the image for the left eye is projected when the filter lets through counterclockwise-polarized light.
*PHOTO: REALD*



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SPECIAL REPORT: 3-D AT HOME

# tools & toys

## NEW DIMENSION

Here's what you need for home theater in the round

1 3-D FLAT-SCREEN TV *(US $2000 to $7000)* The consumer electronics industry has so far lined up behind a single 3-D TV methodology—a regular HD screen with an inexpensive infrared-signal emitter on top, though other types of synchronization emitters, including Bluetooth and RF, can also be found. The signal emitter sends out chirps every 8.3 milliseconds that tell "active" 3-D LCD glasses to successively darken the right lens and then the left, and so on. This keeps down the cost of adding 3-D for manufacturers. Make sure your glasses and TV use the same type of signal.

1. **Sony Bravia KDL-HX800** http://www.sony.com; US $2650

2 3-D BLU-RAY PLAYER *($250 and up)* In December, with the promise of an HDMI cable that would carry as much data as the highest-definition 3-D would require, the Blu-ray Disc Association announced its 3-D specs. That means any 3-D HD Blu-ray player on the market today that sports the 3-D Blu-ray logo will support the highest standard definition for 3-D content—1080p 3-D to both eyes at 240 frames per second—and will also spin regular Blu-ray discs and those stacks of DVDs and CDs in your media cabinet. In addition, some late-model Blu-ray players can upgrade to full HD 3-D in firmware.

3 3-D–ENABLED CABLE OR SATELLITE SET-TOP BOX *(cost varies depending on subscription)* The bad news: For at least the next few years, cable and satellite set-top boxes won't match the full HD resolution to each eye that 3-D Blu-ray discs do (1080p). The good news: This bit of hardware probably doesn't need replacing, just a (typically free) firmware upgrade.

Box makers have for the moment pushed to keep their 3-D and 2-D content the same size image with the same number of frames per second. Inevitably, it's 3-D's resolution that suffers. "Side-by-side 3-D" (which DirecTV uses) squishes the images seen by the left and right eye into a standard high-def frame (making the image that each eye sees 960 by 1080 instead of the full-HD 1920 by 1080), while "top/bottom 3-D" does the same trick in the vertical dimension. In both cases, the set-top box splits up the image being transmitted and fills the whole of your TV screen with the left eye's image while syncing with the active glasses to darken the right eye, and then vice versa.

4 HDMI 1.4 CABLES CONNECTING TO THE TV *($40 each and up)* The cable connecting your 3-D TV to the source of 3-D programming—whether it's a 3-D–enabled Blu-ray player or cable set-top or satellite box—should be a high-speed (1.4) HDMI cable, says Brian Markwalter of the Consumer Electronics Association. Watch out for stores that are still stocking the lower-speed standard (1.3) cables, which should

TV: SONY; SCREEN IMAGE: DISNEY

**2. Panasonic DMP-BDT350**
http://www.panasonic.com; $400

**3. DirecTV 3-D set-top box**
http://www.directv.com

**4. Belkin HDMI cable**
http://www.belkin.com; $40

**5. XpanD X103 3-D glasses**
http://www.xpandcinema.com; $150

### SAMPLE SHOPPING LIST

| | |
|---|---|
| One 3-D–enabled HD television | US $2650 |
| Two HDMI 1.4 cables (TV to Blu-ray; TV to set-top box) | $80 |
| One 3-D–enabled Blu-ray player | $400 |
| One 3-D–enabled set-top box | Free or monthly surcharge |
| Four pairs of 3-D glasses | $600 |
| **TOTAL** | **$3730** |

have faded from the market after the new cables came out in the second half of last year. The older cables may not be able to handle the increased data rate of full HD 3-D video.

5 ACTIVE 3-D GLASSES (*$150 to $200 per pair*) With the exception of LG's anomalous LD950 LCD panel—which requires merely the same cheap polarized glasses found in most 3-D movie theaters today—every consumer 3-D television in the marketplace uses active LCD glasses to achieve the optical illusion of depth. Turning each eye's lens dark and transparent again 60 or so times per second—and alternating that with another 60 or so "winks" per second in the other eye—active 3-D glasses give the relatively slow brain the impression of depth from the flat screen. You'll know that 3-D TV has really caught on when high-end eyewear designers start making frames for active 3-D glasses that look as flattering on the face as they make the television's frame look to you.

—M.A.

CLOCKWISE FROM TOP LEFT: PANASONIC; DIRECTV; JOHN RENSTEN/GETTY IMAGES; XPAND; BELKIN

## Could "Vertical Vergence" Threaten the Future of 3-D in the Home?

**In all likelihood,** your experience with 3-D to date has been in a movie theater, squeezed into a chair that keeps you sitting upright. But how often do you sit like that at home?

"People lie on the couch or put their arm on the armrest and tilt their head to the side," says optometry and vision-science professor Martin Banks of the University of California, Berkeley. And that might make the 3-D TV experience unpleasant for some viewers.

Banks says the perceived closeness of the Na'vi or the distance to the faraway "Scorpion" gunship in *Avatar* arises from the horizontal parallax between the camera's "left eye" and "right eye" perspectives, which in turn presumes that the imaginary line connecting a person's two eyes is horizontal—chin up, eyes straight.

Tilt your left ear down while watching a 3-D movie, though, and your brain has to compensate for the skewed parallax now coming off the screen by rotating the left eye upward and the right eye downward. This "vertical vergence" eye motion isn't a problem with 2-D programming (which is flat and thus has no parallax) or when you're watching the real world (whose depth comes from real parallax, which doesn't depend on any particular position of the head).

But with 3-D programming, Banks says, "the eyes don't like doing that. They can do it, but it's very tiring." He says he sees no evidence of any damage caused by vertical vergence, but initial tests in his lab suggest that some viewers' responses to going cockeyed with vertical vergence could range from feelings of discomfort to nausea.

Banks and his co-investigators are now researching this and other possible wrinkles and complications of 3-D stereoscopic technology in the home. If vertical vergence does make 3-D home viewing unpleasant for many, it may have a big impact on the market. After all, who wants a television technology to act like a schoolmarm out of Central Casting who snaps her yardstick at any student who isn't sitting up straight?

*—M.A.*

# tools & toys

## 3-D VIDEO GAMES

### As usual, video games lead the way

THE WORLD of 3-D video games, any gamer will tell you, is almost as old as video games in color: Nintendo titles in the late 1980s like *Rad Racer* and *3-D WorldRunner* each had 3-D modes that used red-and-blue passive eyeglasses to produce images that jumped off the screen just like 1950s-era movie monsters.

What's new in 2010 is the prospect of 3-D games running on the new 3-D television sets coming onto the marketplace. Sony is promoting 3-D video games on its PlayStation 3—firmware upgradable to run on 3-D TVs—such as *James Cameron's Avatar* and *Invincible Tiger: The Legend of Han Tao*. On the other hand, some video-game makers are holding back, preferring the old-fashioned method that uses colored glasses, in new titles such as *Batman: Arkham Asylum* and *Skate 2*.

Perhaps most tantalizing was Nintendo's announcement at the E3 games conference in June that it'll soon be releasing the 3DS, a glasses-free 3-D handheld game player—the follow-up to the company's phenomenally popular DS portable. As Nintendo revealed at E3, the 3DS uses a technology from Sharp that relies on a "parallax barrier," in which ultrathin vertical slits down the display screen mask some pixels from one eye and different pixels from the other. Crucially, the 3-D technique works only in a limited range of viewing angles and distances from the screen, which is why the technology is being rolled out in a handheld device. According to one interview with Nintendo president Satoru Iwata in the lead-up to E3, the company is also considering rolling out a 3-D–ready Wii 2 console once the number of households with 3-D televisions crosses the 30 percent threshold.

As always, a less expensive, less intense gaming experience can be had on laptops and desktop PCs. For under US $1000 you can get a smaller, cheaper monitor and a 3-D graphics card, such as the Nvidia 3-D Vision. As of April, Nvidia's Web site listed more than 100 PC video games that could be played in 3-D.

Scott Steinberg, CEO of Seattle-based tech consulting firm TechSavvy Global, says that despite all the hype, 3-D still doesn't eliminate or even lessen the chief challenge to any game designer: creating great game play. Even the most eye-popping visual effects, he said, will become commonplace. Designing play that appeals to the undefinable "wow" factor that has always set classic games apart from the pack will still be the ultimate goal.

"You can't simply take a 2-D game, throw a 3-D effect on it, and call it a day," he says. "The risk for the game maker is they invest so much in creating such a visually enticing landscape to the detriment of the product's game play."

—M.A.

**Sony PlayStation 3**
US $300 and up
http://playstation.com

1 **VIDEO-GAME CONSOLE:** With one downloadable firmware upgrade, Sony's **PlayStation 3** ($300) will support 3-D video-game titles. As of mid-May, neither Microsoft nor Nintendo had announced upgrades of their **Xbox 360** ($200) and **Wii** ($200) systems to do 3-D gaming on this year's new line of HD 3-D televisions. Of course, old-fashioned red-blue anaglyph glasses—the kind used for 1950s horror movies—can be used for a 3-D effect with any console and any television. In fact, Majesco Entertainment's new shooter *Attack of the Movies 3-D* ($30 Xbox, Wii) draws inspiration from the 3-D creature features of yesteryear—and gives its users four pairs of kitschy plastic gel glasses for the full dimensional experience.

2 **CONSOLE GAMES:** Sony is going all out for 3-D gaming with its PlayStation 3, but "the question is, when will there be games?" asks Seattle-based video-game industry analyst Scott Steinberg of TechSavvy Global. ***James Cameron's Avatar*** ($30) is, not surprisingly, an early entry into the still tiny pool of 3-D PlayStation games available. Steinberg said he's seen industry demos of 3-D enhancements to other marquee titles such as the racing game ***Gran Turismo 5*** ($60) and ***Little Big Planet*** ($60). But the most impressive console game he's seen yet is a downloadable shooter called ***Super Stardust HD*** ($10). "This is *Asteroids* with better graphics," he says. "It's immediately arresting. There are literally thousands of objects on the screen. So when you add 3-D and depth of field, you can see each object's position in relation to the others."

*Super Stardust HD*

3 **DESKTOP PC AND 3-D MONITOR:** If you like gaming and 3-D, Nvidia is currently offering the cheapest way into the 3-D world with its **3-D Vision GeForce** graphics card enhancement package ($200 and up), which with a fast enough monitor (such as the 120-hertz, 22-inch **Samsung SyncMaster 2233RZ** at $300) would still bring your budget 3-D setup in at well under four figures. With recent model GeForce cards (details on Nvidia's Web site), a 3-D Vision's infrared emitter module plugs into a USB port and chirps its "left-eye, right-eye" syncing signal to Nvidia's active 3-D glasses while it pipes 3-D signals to the monitor. And unlike Sony's PlayStation 3, which boasts only a handful of full HD 3-D games, there are more than a hundred Nvidia 3-D Vision–enabled games for the PC. Some streaming noninteractive content—such as this past spring's golf Masters Tournament—is also 3-D Vision–ready. Of course, whatever desktops can do, laptops will be doing soon. In November, Asus announced the first Nvidia 3-D Vision gaming laptop.

FROM TOP: SONY; HOUSEMARQUE; NVIDIA

# technically speaking

BY PAUL McFEDRIES

MICK WIGGINS

# Hacking the Planet

I think one should be very, very careful about throwing iron filings into the troubled waters. —novelist Ian McEwan

SOLUTIONS TO the problem of man-made climate change are legion, but none have quite the audacity, the sheer technological chutzpah, of the various ideas that fall under the rubric of *geoengineering*. This term, which has been around for several decades, refers to the deliberate, planetwide manipulation of the climate to reduce or reverse the effects of global warming. It's also called **planetary engineering**, **climate engineering**, **climate intervention**, or more to the point (and somewhat hopefully), **climate restoration**. Scientists who apparently also moonlight as poets call it **gardening the Earth**.

The scientific, technological, political, and even moral aspects of geoengineering are fascinating, but they're well beyond the scope of this humble column. My goal here, as usual, is to focus on the new language being generated by **geoengineers** and others in this burgeoning field, and there's plenty of it.

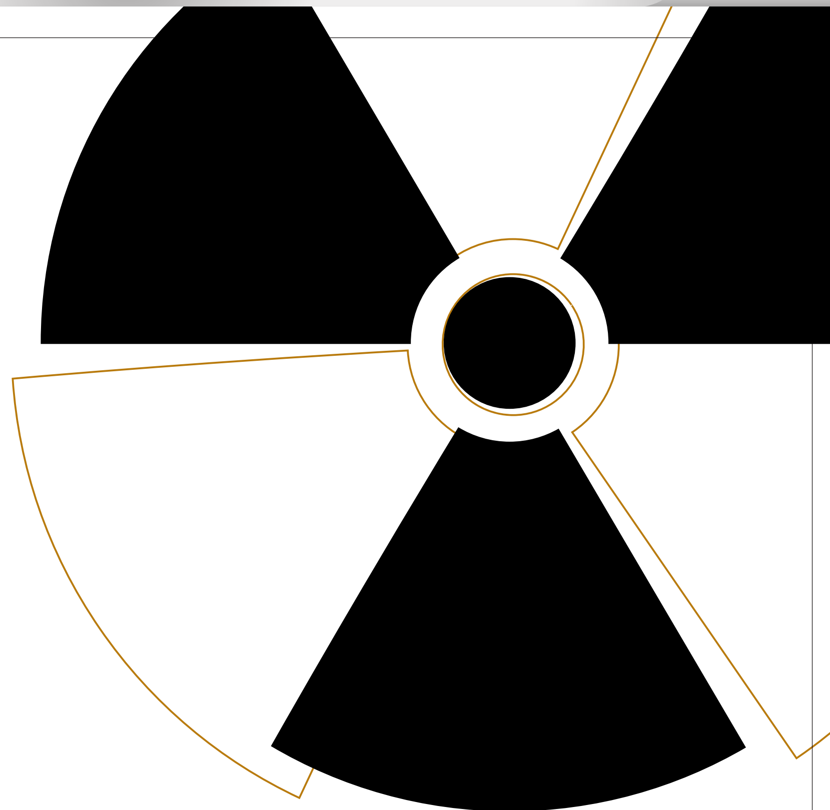
The overall goal of **solar radiation management** (or **SRM**)—the various schemes to reflect sunlight back into space and thus reduce global warming—is **global dimming**, which is the gradual reduction in the amount of sunlight reaching Earth's surface. One way to do this is to increase Earth's overall reflectivity, which is also called its albedo, so this form of **planet hacking** is known as **albedo engineering**. Examples of proposed projects include **cloud brightening**, increasing the reflectivity of marine clouds (also called **cloud whitening**); creating a **stratoshield** through **stratosphere doping**—pumping sulfur dioxide into the stratosphere to mimic the effects of a volcanic eruption (this is also called the **Pinatubo option**, after the famous Mount Pinatubo volcano, which erupted spectacularly in 1991, causing global temperatures to drop by an estimated 0.5 °C); lacing the atmosphere with **reflective aerosols**, which are tiny, reflective metal flakes that could be mixed with jet fuel and deployed through jet exhaust (although this would certainly lead to trouble with a group of conspiracy theorists known as **chemmies**, who believe that jet contrails are laced with chemicals, a phenomenon they call **chemtrails**); deploying a **space sunshade**, which would use space-based mirrors to deflect incoming sunlight; creating **cool roofs** by painting them white; and **Arctic engineering**, which aims to maintain or increase sea ice levels in the Arctic, because white sea ice reflects a great deal of sunlight.

The other pillar of geoengineering, **greenhouse-gas remediation**, aims to take greenhouse gases out of the atmosphere and thus reduce global warming by allowing reflected sunlight to return to space. Carbon is the main culprit here, and **carbon engineering** usually involves two operations: **carbon capture**, which is the removal of carbon from the atmosphere (and, depending on where and how it happens, may also be called **ocean capture** or **air capture**), and **carbon sequestration**, which is the long-term storage of captured carbon. These two procedures are linked as **carbon capture and storage**, or **CCS**. Strategies include adding nutrients to the ocean to increase the number of organisms that can capture carbon, known as **ocean nourishment** (when the nutrient is iron, this technique is also called **iron fertilization**); making **artificial trees** with plastic "leaves" that capture carbon; creating **carbon sinks**, reservoirs that store carbon; injecting carbon into underground geological structures (**geosequestration**) or into biological entities (**biosequestration**), particularly a form of charcoal called **biochar**; and pumping carbon into the deep ocean, where it dissolves (**ocean dissolution**).

The goal throughout is to manage Earth's **heat budget**, the amount of heat that comes in from the sun less the amount reflected back into space. Will these ideas cause more problems than they solve? Didn't monkeying with the climate get us into this mess in the first place?

These are tough questions, and I haven't got any answers. However, we owe it to ourselves to understand what some are calling a **rational environmentalism**, and knowing the lingo that scientists and politicians are throwing around is a good first step. ❑

BY SALLY ADEE + ERICO GUIZZO
ILLUSTRATIONS BY BRYAN CHRISTIE DESIGN



# Reactors Redux

**NUCLEAR-REACTOR DESIGN IS POISED FOR A DESPERATELY NEEDED REVIVAL. HERE ARE SEVEN CONTENDERS**

MORE THAN HALF A CENTURY AGO, the first commercial nuclear power reactors went critical in the United Kingdom and the United States. In the decades since, technology has brought us 3-billion-transistor chips, manned spaceflight, and violin-playing robots. Nevertheless, the basic design of commercial nuclear power reactors has changed not a whit. They seem to be trapped in a land that technology forgot.

Yes, conservatism can be a good thing, perhaps nowhere more so than in the design of nuclear reactors. Electric utilities aren't known for daring, and you can't reasonably expect them to risk several billion dollars on a reactor without a track record. On the other hand, you can't pin hopes for a nuclear renaissance on designs that were fresh back when color TV and transatlantic jet travel were novelties. You need the promise of something much better, and no fewer than a dozen advanced reactor designs are in the running to offer it.

The backers of these designs are eyeing potentially enormous businesses, as "waking giant" countries China and India pursue major electrification schemes. In the United States and Europe, a significant shift to nuclear is far from assured, but several factors seem to be pushing that option, including climate change concerns and awareness of the hidden costs of fossil fuels.

The new reactor designs fall into three categories. First, there are the new light-water reactors, which aren't radically different from what's out there right now but add better safety features. Then there are the small modular reactors that produce less than 300 megawatts but can be scaled up. Need more power? Just add more modules to your plant. Finally, there are the really-out-there designs, known in the industry as Generation IV.

There are too many worthy, intriguing designs for us to describe here. So, after talking to a dozen nuclear experts, we simply chose seven reactor designs that struck us as the most innovative and interesting. We picked reactors of different kinds and at different development stages, including those that are only a hair's breadth from regulatory approval and others that are literally still on the drawing board.

Did we leave out a new reactor design that you think beats all these here? Will new reactors reenergize the nuclear industry? Go to http://spectrum.ieee.org/newnuclear and tell us what you think.



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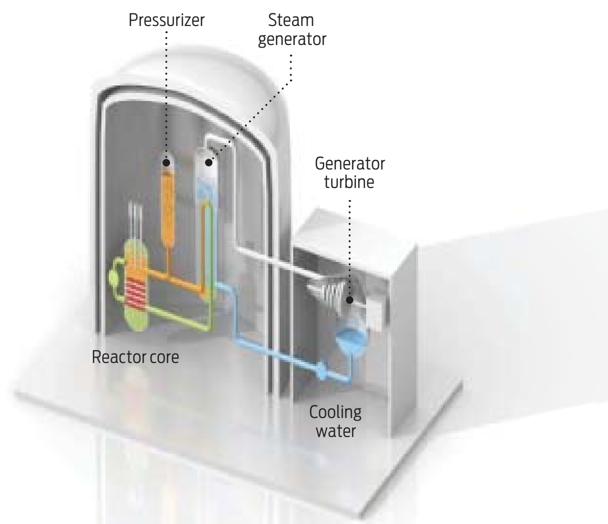
NEW + IMPROVED

# Next-Gen Light-Water Reactors




**NUCLEAR WORKHORSE** The pressurized-water reactor design has been used for decades. Here's how it works

1 **A PWR core** consists of hundreds of 4-meter-long metal pillars called fuel assemblies. Each assembly holds multiple rods that contain pellets of enriched uranium (typically 3 to 5 percent uranium 235 and the rest uranium 238). The core sits inside a metal container, or pressure vessel, which is filled with water.

2 **Inside the core,** nuclei of uranium 235 undergo fission, emitting neutrons. These fast neutrons would normally escape the core without interacting with other nuclei, but the water, which acts as a moderator, slows them down, which lets more of them hit and split other uranium 235 nuclei, thereby generating more neutrons.

3 **This fission chain reaction** releases vast amounts of energy, raising the temperature of water within the core to about 315 °C. That heat is used to produce steam in a secondary water system, and the superheated steam spins a turbine connected to a generator to produce electricity. The principle of steam driving a turbine remains constant in most nuclear reactor designs.

4 **The water within** the reactor also has a safety function: As the water heats up and becomes less dense, its ability to slow neutrons down naturally decreases, and the chain reaction subsides. The water also prevents the neutrons from propagating too far. Additional control and safety features include neutron-absorbing control rods that contain boron, which may be inserted into the core to shut it down.

5 **A PWR typically** needs to be refueled about every two years. The spent fuel, consisting of leftover uranium 235 and other highly radioactive waste, can be sent to permanent storage (in a water-filled pool for approximately 10 years and then in dry casks housed on-site), or it can be reprocessed. Reprocessing separates out the uranium that didn't undergo fission for later use and also plutonium, which can be recycled into mixed-oxide (MOX) fuel. By-products of reprocessing include plutonium 239, which can be used for making nuclear weapons. For this reason, some experts see reprocessing as a proliferation risk.

TO UNDERSTAND THE NEW GENERATION of nuclear reactors, you need to start with the basics. Think of a reactor as a tightly grouped array of thin, 4-meter-long, heat-emitting rods stacked in the center like a bunch of rigid metal asparagus. Surrounding those rods is a pressure vessel full of ordinary, or "light," water. Each rod is filled with uranium fuel pellets, which when close to one another emit neutrons and lots of heat. The water in your basic thermal nuclear reactor needs to do three things: get hot; cool the nuclear fuel, which would otherwise overheat and cause a meltdown; and reduce the speed of the neutrons emitted by the nuclear reactions in that fuel. Here's why. When a neutron hits a uranium nucleus, that nucleus then fissions into two smaller nuclei while emitting more neutrons. Then those neutrons hit other uranium nuclei, which fission, emitting neutrons that hit other nuclei, and so on. That's a nuclear chain reaction. It seems counterintuitive, but the neutrons must be slowed—the technical term is "moderated"—to increase the rate at which they split the uranium nuclei they encounter in the fuel rods. Without the water to moderate them (graphite is another commonly used moderator), the neutrons would move too quickly for the uranium nuclei to absorb them, and the nuclear reaction would simply fizzle.

In a light-water reactor, ordinary water accomplishes both cooling and moderation. There are two main types. Pressurized-water reactors, or PWRs, are associated historically with Westinghouse Electric Corp., in which the vessel housing the fuel rods is kept at 160 atmospheres, so the water flowing past the core never turns to steam. The other kind are boiling-water reactors, pioneered for commercial uses by General Electric, which work, as the name suggests, by boiling the water that cools the reactor. Right now PWRs vastly dominate the nuclear landscape. The heat is used to produce steam that drives a turbine, which spins a dynamo to generate electricity. In both types, the steam is always produced by water flashing on extremely hot pipes.

Given their long history, light-water reactors won't be going away anytime soon. One of the leading contenders for the next generation belongs (unsurprisingly) to Westinghouse, in the form of a souped-up PWR known as the AP1000. So far, it's the only new PWR design that's been approved by the U.S. Nuclear Regulatory Commission. (Although other countries have nuclear certification processes of their own, some borrow heavily from the NRC, which is influential internationally.) This new breed of PWR, which also includes a French model called an EPR, is known in the industry as Generation III or III+.



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# WESTINGHOUSE AP1000

Passive safety features will shut down this reactor without any power, pumps, or people

## HOW IT WORKS:

The AP1000 core is similar to standard PWR cores: The fuel produces heat that turns water into steam, which drives a turbine.

## ADVANTAGES:

The reactor's designers have significantly improved the safety features on an otherwise standard PWR. Whereas conventional reactors rely on motor-powered valves and water pumps to deal with accidents, the amended AP1000 design has safety systems that rely on airflow, pressure changes, and gravity. For example, if a coolant pipe breaks, both the pressure and temperature rise inside the containment vessel **[1]**. Those changes trigger a water-flooding emergency system **[2, 3, 4]**. The water inside the sealed containment vessel heats up and turns into steam. The steam rises to the top, where the steel shell has been cooled by air circulating around the vessel. Thus cooled, the steam condenses back into water. This cycle reduces the pressure and temperature, and the nuclear chain reaction ends. Unlike other pressurized-water reactors, the AP1000 needs no safety features beyond the passive ones.

## DISADVANTAGES:

Water—particularly superheated water—corrodes metal, and so the pipes, joints, and other conduits must be periodically checked, maintained, and replaced. According to one estimate, the AP1000 will use as much water per megawatt as a regular PWR.

## TIME FRAME:

Westinghouse is building four AP1000s in China. Construction on Sanmen 1, which will be the world's first operating AP1000, began in March of last year and should be completed in 2013. Three U.S. utilities have announced plans to build six AP1000 units, with one scheduled for commercial operation in 2016. However, construction can't start until the NRC grants the reactor its final approval, which the agency says will not happen before mid-2011.


**MANUFACTURER:** *Westinghouse Electric Co.*
**HQ:** *Cranberry Township, Pa.*
**TYPE:** *Pressurized-water reactor*
**POWER:** *Thermal, 3415 MW; electric, 1117 MW*
**FUEL:** *Enriched uranium clad in fuel assemblies similar to those in ordinary PWRs*
**REFUELING:** *Every 18 to 24 months*
**COOLANT:** *Water*
**MODERATOR:** *Water*
**WASTE:** *Spent fuel, consisting of leftover uranium 235 and other highly radioactive waste, similar to standard PWR waste.*

# EPR

Europe's Evolutionary Power Reactor will be the world's largest pressurized-water reactor

## HOW IT WORKS:

An EPR core is similar to a standard PWR core, but larger.

## ADVANTAGES:

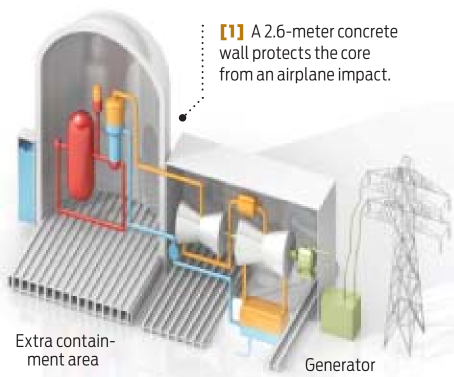
The reactor is a descendant of the time-tested N4 and Konvoi reactors, the most modern reactors in France and Germany. An EPR's turbines can be maintained while it is in service; its manufacturers claim this will make for very little downtime and a lifetime of 60 years. The Union of Concerned Scientists has referred to the EPR as the only new reactor design under consideration in the United States that "appears to have the potential to be significantly safer and more secure against attack than today's reactors" **[1]**. The EPR also has the highest-ever efficiency (36 percent) in converting thermal energy into electric compared to other light-water reactors, whose efficiency typically runs at about 33 to 34 percent.

## DISADVANTAGES:

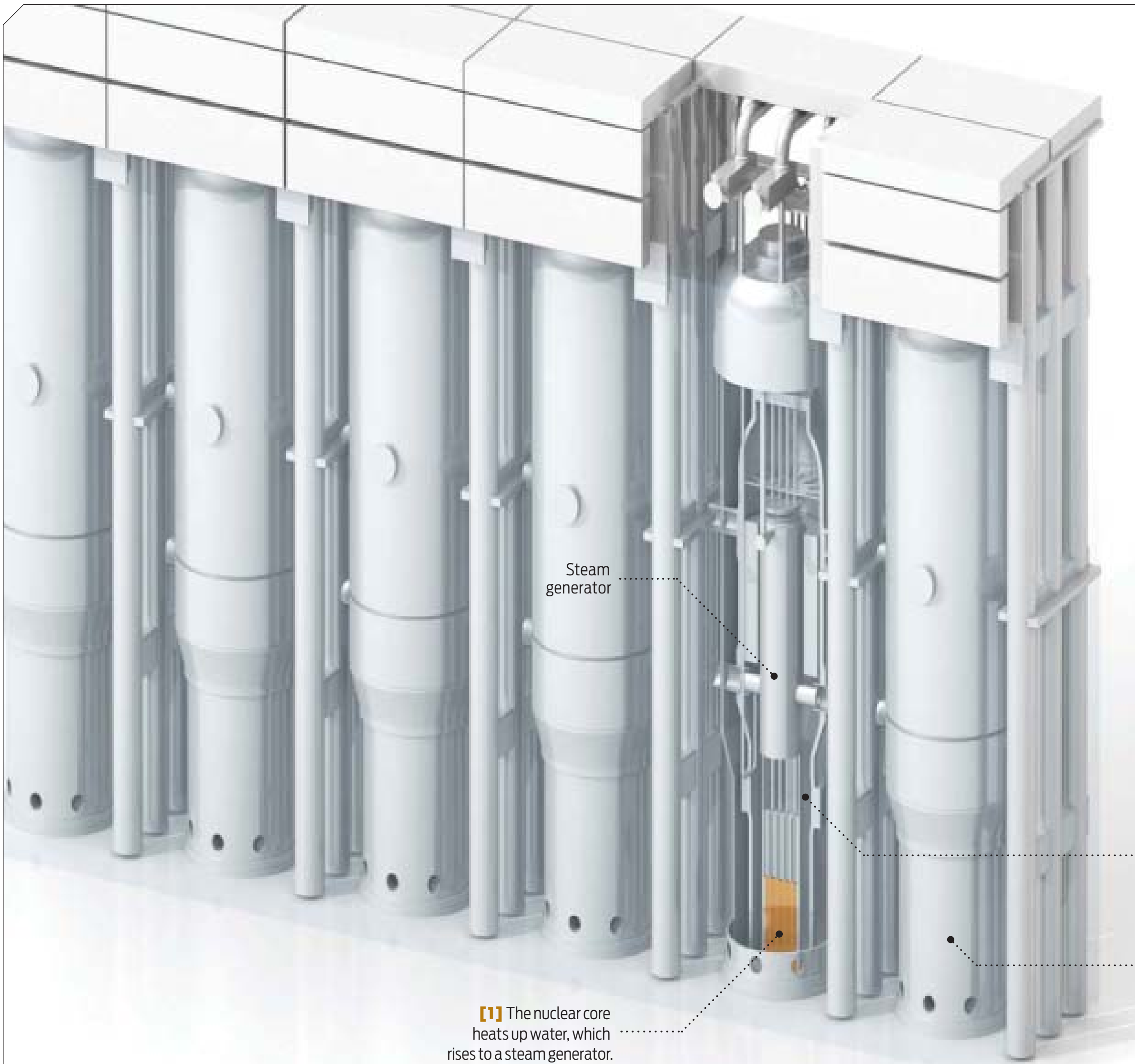
Some analysts have expressed doubts that the EPR is the world's safest reactor. Their main concern is the spent fuel: The reactor's higher burn-up rate makes the waste more radioactive, raising concerns about proliferation.

## TIME FRAME:

Four EPRs are now under construction: one each in Finland and France and two 1650-MW units in Taishan, China, which is already planning to build two more. The Finnish plant will be the world's first EPR and the first Generation III+ reactor. A handful of U.S. utilities plan to build at least four EPR plants after the NRC finishes its review.




**MANUFACTURER:** *Areva* // **HQ:** *Paris* // **TYPE:** *Pressurized-water reactor* // **POWER:** *Thermal, 4500 MW; electric, 1650 MW* // **FUEL:** *The reactor can use 5 percent enriched uranium oxide clad in fuel rods similar to those of conventional PWRs. It can also use fuel with up to 50 percent mixed uranium plutonium oxide.* // **REFUELING:** *Every 24 months, at most* // **COOLANT:** *Water* // **MODERATOR:** *Water* // **WASTE:** *Spent fuel, consisting of leftover uranium 235 and other highly radioactive waste.*




**MANUFACTURER:** *NuScale Power*
**HQ:** *Corvallis, Ore.*
**TYPE:** *Light-water reactor*
**POWER:** *Thermal, 160 MW; electric, 45 MW for one reactor module. A full-scale plant would have 12 to 24 modules, or an electric power capacity of 540 to 1080 MW.*
**FUEL:** *Nearly 5 percent enriched uranium in 1.8-meter-long fuel assemblies similar to those used today in standard light-water reactors*
**REFUELING:** *Every 24 months*
**COOLANT:** *Water*
**MODERATOR:** *Water*
**WASTE:** *Spent fuel, consisting of leftover uranium 235 and other highly radioactive waste, similar to standard PWR waste.*

SIZE MATTERS

# Small Modular Reactors

ONE OF THE TRADITIONAL selling points of nuclear power has been the high power levels available from a single plant—gigawatts rather than hundreds of megawatts. A single 1-gigawatt electrical plant could power about 1 million homes. Nowadays, though, the multibillion-dollar costs of building such a mammoth plant seem scary to investors. Smaller, modular reactors could provide scalable, emissions-free power at lower financial risk. They could also do this in remote areas off the grid. Yet another advantage is that one of the modules could be shut down for maintenance while others keep generating, avoiding long periods of downtime, which can be fantastically costly.

## NuSCALE A modular light-water reactor designed to replace coal- and gas-fired plants

**HOW IT WORKS:**
The nuclear fuel assemblies sit inside a long core vessel, which in turn is housed in a secondary containment vessel immersed in water. Unlike conventional light-water reactors, which require large pumps to circulate water through the core, the NuScale reactor is based on convection: The fuel heats up the water [1], which rises to the top of the core vessel, transfers the heat to steam generators, and cools down, descending to the bottom and repeating the cycle [2]. The steam drives electrical generators. After losing energy, the steam is cooled back into liquid in condensers, after which it flows again into the steam generators and the process repeats.

**ADVANTAGES:**
The design is basically a passive version of traditional light-water reactor technology. The cooling system relies on water convection alone and doesn't require pumps. The plants are scalable—they can have a single reactor module or up to 24. Each module can be refueled individually, without affecting other modules. The modules can be largely manufactured off-site and transported by barge, truck, or rail, reducing construction time. Finally, the fuel and steam generator are housed inside a water-submerged steel vessel [3], which has a greater ability to withstand pressure and dissipate heat than the building that houses a traditional PWR.

**DISADVANTAGES:**
In a full-size plant, the operator would have to manage, inspect, and maintain a dozen or more reactors. To be refueled, reactor vessels would have to be removed from the containment receptacle, transported to a servicing area using an overhead crane, then partially disassembled and refueled using remotely operated machines.

**TIME FRAME:**
NuScale plans to apply for design certification with the NRC in early 2012. At about the same time, any utilities interested in building a plant would have to apply for construction and operation licenses. NuScale is in talks with several undisclosed utilities and expects a first plant to be operational in 2018.

# HYPERION POWER MODULE

It could power a small town or a remote community off the electrical grid

### HOW IT WORKS:

The Hyperion power module (HPM) is a fast reactor. This class of reactors does not need a moderator. In a standard PWR—known as a thermal reactor—water is essential, because it slows down neutrons so they can fission other uranium atoms and produce more neutrons. The advantage of using a moderator like water is that you can start a chain reaction using a relatively small mass of uranium fuel. By contrast, a fast reactor uses a larger mass of fuel, which releases many more neutrons. But here it's no longer necessary to slow them to unleash a chain reaction. Also helping drive the process is the coolant, which in the HPM is a lead bismuth mixture **[1]**. Besides not slowing the neutrons, it transfers heat more efficiently to the turbine system.

### ADVANTAGES:

The lead bismuth mixture is potentially safer than other liquid-metal coolants: Lead doesn't react with air or water. Because it's a fast reactor, the HPM doesn't consume vast amounts of water, making it attractive for areas where water is scarce or unavailable. Uranium nitride fuel **[2]**, which replaces standard uranium oxide, is less prone to cracking at high temperatures. The company claims that a vessel breach would simply leak liquid metal, which would immediately solidify instead of dispersing radioactive steam as a PWR would. The reactor would be built underground and have secondary coolant loops and control rods for extra safety **[3, 4, 5]**.

### DISADVANTAGES:

Very few fast reactors have generated power commercially. Most are used for research and in military submarines. Hyperion's uranium nitride fuel and its lead bismuth coolant have been individually tested in research reactors, but never together. The company has yet to demonstrate a fully operational prototype. Finally, there's no guarantee that Hyperion will be around to make good on its promise to pick up the nuclear waste.

### TIME FRAME:

Hyperion says it already has more than 150 customers queued up, including mining and telecommunications companies in the Czech Republic, South Africa, the UK, and the United States, but these buyers will have to wait for the necessary licenses. Certification of the HPM reactor in the United States might take three to five years once the company submits an application.


**MANUFACTURER:** *Hyperion Power Generation*

**HQ:** *Denver*

**TYPE:** *Liquid-metal-cooled reactor*

**POWER:** *Thermal, 70 MW; electric, 25 MW*

**FUEL:** *Stainless steel fuel pins confine solid-ceramic uranium nitride pellets. The fuel is enriched to just under 20 percent. (Typical PWR fuel is 3 to 5 percent. The Nuclear Non-Proliferation Treaty defines 20 percent enrichment as the lower limit for "special nuclear material," the level at which it is considered "weapons usable.")*

**REFUELING:** *None. Entire unit is replaced every 8 to 10 years*

**COOLANT:** *Liquid lead bismuth (liquid-metal-cooled reactors are usually sodium cooled)*

**MODERATOR:** *No moderator (it's a fast reactor)*

**WASTE:** *Hyperion claims the HPM works as a disposable reactor: Instead of frequently replacing spent uranium with fresh fuel, refueling in this case means replacing the entire 20-metric-ton core with a brand new one. And Hyperion says it will take care of the used one.*



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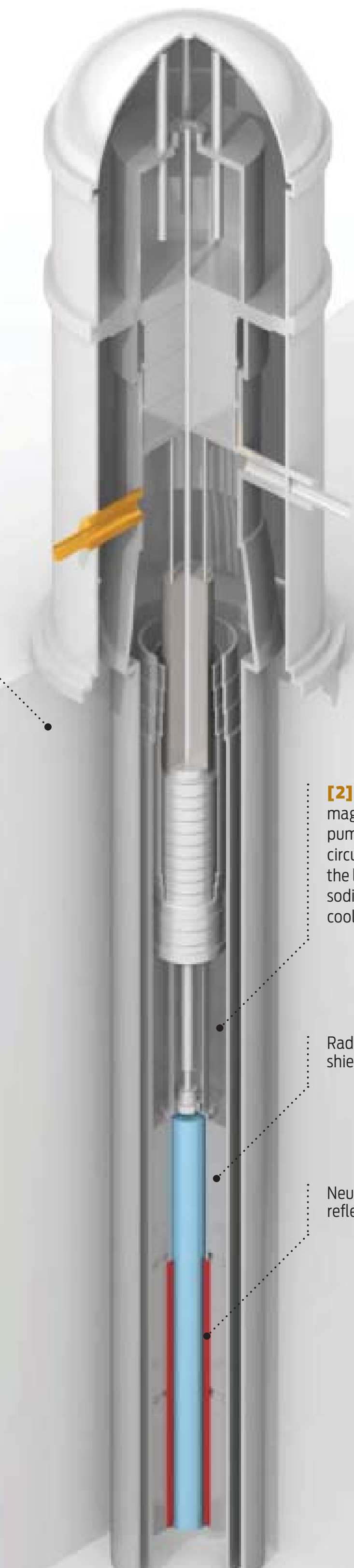
WAVE OF THE FUTURE?

# Generation IV Reactors

THE MOST EXOTIC designs, the Generation IV reactors, use new kinds of fuel and moderators. And fast-reactor designs do away with the moderator altogether. As a result, they require fuel with higher concentrations of fissile material (plutonium or uranium 235) than do light-water reactors. And a few promise to do something unprecedented—burn not just fuel but also the longer-lived nuclear waste products that have plagued nuclear energy since its inception. The Next Generation Nuclear Plant, a Generation IV design being considered by a consortium of U.S. companies, will likely be cooled by helium and moderated by graphite. The specific technology and leading companies will be announced early in 2011. Other, even more radical reactors include TerraPower's traveling-wave reactor, which the company hopes to build and test in a little over a decade.

## TOSHIBA 4S The four S's in the name stand for super, safe, small, and simple. Think of the reactor as a nuclear battery with a 30-year life

**MANUFACTURER:** *Toshiba*
**HQ:** *Tokyo*
**TYPE:** *Liquid-sodium-cooled fast reactor*
**POWER:** *Thermal, 30 MW; electric, 10 MW*
**FUEL:** *Uranium enriched to about 19.9 percent (just below the 20 percent weapons-usable threshold); the uranium is mixed with zirconium and clad in steel.*
**REFUELING:** *The reactor is sealed and never refueled. When its fuel is exhausted after 30 years, the entire reactor core would be returned to the manufacturer for disposal, and another one could take its place.*
**COOLANT:** *Liquid sodium*
**MODERATOR:** *No moderator (it's a fast reactor)*
**WASTE:** *Spent fuel remains sealed in the core.*

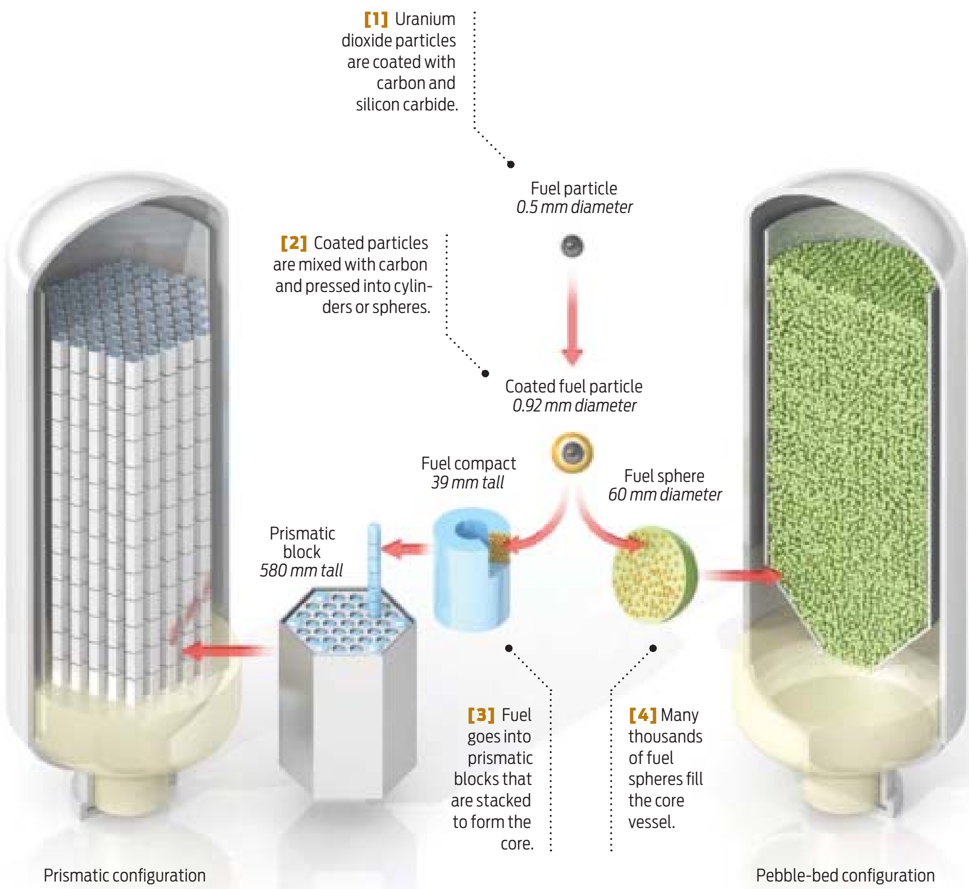



### HOW IT WORKS:
The core, which is long and skinny [1], has a ring-shaped reflector that moves up slowly over time. This shield keeps neutrons contained in a focused area of the core, where the chain reaction takes place. As the ring rises, it slowly burns up the nuclear fuel. For harvesting the heat, the 4S reactor is configured with three loops. In the first, liquid-sodium metal circulates to cool the reactor core. Liquid sodium also circulates in the second loop, which transfers heat to a third, this one containing water and steam to drive a turbine. In the first and second loops, convection makes the liquid metal flow. To improve safety, electromagnetic pumps—with no moving parts—help with circulation [2]. The reactor is designed as a sealed cylindrical vault, which could be buried 30 meters underground to ensure safety against tornadoes and terrorists.

### ADVANTAGES:
The reactor can sit mostly unattended for up to 30 years, in part because the liquid-sodium coolant doesn't corrode the metal pipes and vessels of a reactor the way superheated water does. Also, because the reactor does not have to be pressurized, a pipe rupture would not be explosive. Instead, the molten sodium would merely seep. Like any fast reactor, the 4S could fission some of the longer-lived isotopes in the spent fuel, which would reduce to some degree the quantity of isotopes and also the overall volume of waste.

### DISADVANTAGES:
Sodium is extremely volatile and explodes on contact with water. One of the claimed benefits of this design—the fissioning of long-lived isotopes in the spent fuel—might actually be a weakness. Though the volume of waste product is reduced, the waste itself is much more radioactive and could conceivably be used to create dirty bombs.

### TIME FRAME:
In the United States, Toshiba has had preliminary meetings with the NRC and has submitted preapplication technical reports. The company expects to submit its design for review in late 2012. The NRC will not estimate when it could be approved. The 4S already has some interested parties, including the western Alaska city of Galena (population 599), which plans to apply for a construction license as soon as the NRC grants its approval.




# NEXT GENERATION NUCLEAR PLANT

This Generation IV reactor is designed to produce electricity and also heat for industrial applications

**HOW IT WORKS:**
This reactor's fuel consists of uranium particles known as tristructural isotropic, or TRISO, particles **[1, 2]**. Blocks or spheres containing the TRISO fuel and carbon are arranged into a nuclear core **[3, 4]**, producing a chain reaction. Helium circulates through the core, removing heat. The helium drives a turbine directly, or it can generate steam to turn the turbines. Because the core consists of helium and graphite, it can withstand temperatures of 900 °C and even higher; pressurized-water reactors operate at about 300 °C.

**ADVANTAGES:**
The reactor's higher temperature means it could provide heat to industrial processes such as petroleum refining, chemical manufacturing of plastics and fertilizers, and hydrogen production, thus helping to reduce carbon emissions and use of oil and natural gas. Despite its higher temperature, the reactor operates at one-fifth the power of a PWR. That reduced power density enhances overall safety. What's more, additional heat naturally increases the carbon's ability to absorb neutrons, so the carbon acts as a passive safety mechanism capable of shutting down the core. Fuel particles can withstand up to 1600 °C, so even in an accident the fuel would remain intact and limit fallout. High-temperature gas-reactor prototypes have been demonstrated in Germany and China.

**DISADVANTAGES:**
Much testing is yet to be done. Fuel pellets need to be evaluated under heavy neutron bombardment, and so does the graphite that would form the core. The high-temperature materials to hold the helium—nickel-based superalloys—also must be fully characterized and tested in extreme conditions. Reactor physics must be simulated and validated. The reactor's core would contain a lot of graphite that ideally would be recycled, a process that might prove costly.

**TIME FRAME:**
In early 2011, the U.S. Department of Energy expects to choose between proposals from General Atomics and Westinghouse. Further design work should take 8 to 10 more years.

**MANUFACTURER:** *Two designs, commissioned by the U.S. Department of Energy under the Next Generation Nuclear Plant program, are currently under development, one by a consortium led by General Atomics, in San Diego, and another by a consortium led by Westinghouse, in Cranberry Township, Pa.*

**TYPE:** *High-temperature gas-cooled reactor*

**POWER:** *Thermal, 250 to 600 MW; electric, 112 to 270 MW*

**FUEL:** *Microscopic particles of uranium dioxide coated with carbon and silicon carbide. These spheres, known as tristructural isotropic, or TRISO, particles, are then mixed with lots of graphite and pressed into one of two possible geometries: spheres the size of tennis balls (the pebble-bed design) or sticks the size of a piece of chalk that are inserted into hexagonal graphite blocks (the prismatic design).*

**REFUELING:** *The spent fuel is continuously replaced without shutting down the reactor. In the pebble-bed type, TRISO balls are removed from the bottom to have their fission levels measured, and new balls are added to the top. In the prismatic reactor, thousands of hexagonal blocks are stacked and their TRISO fuel sticks replaced periodically.*

**COOLANT:** *Helium*

**MODERATOR:** *Graphite*

**WASTE:** *The spent fuel consists of balls (in the pebble-bed reactor) and sticks (in the prismatic reactor) containing leftover uranium that didn't undergo fission and other radioactive material; the waste would be stored in metal casks on-site.*



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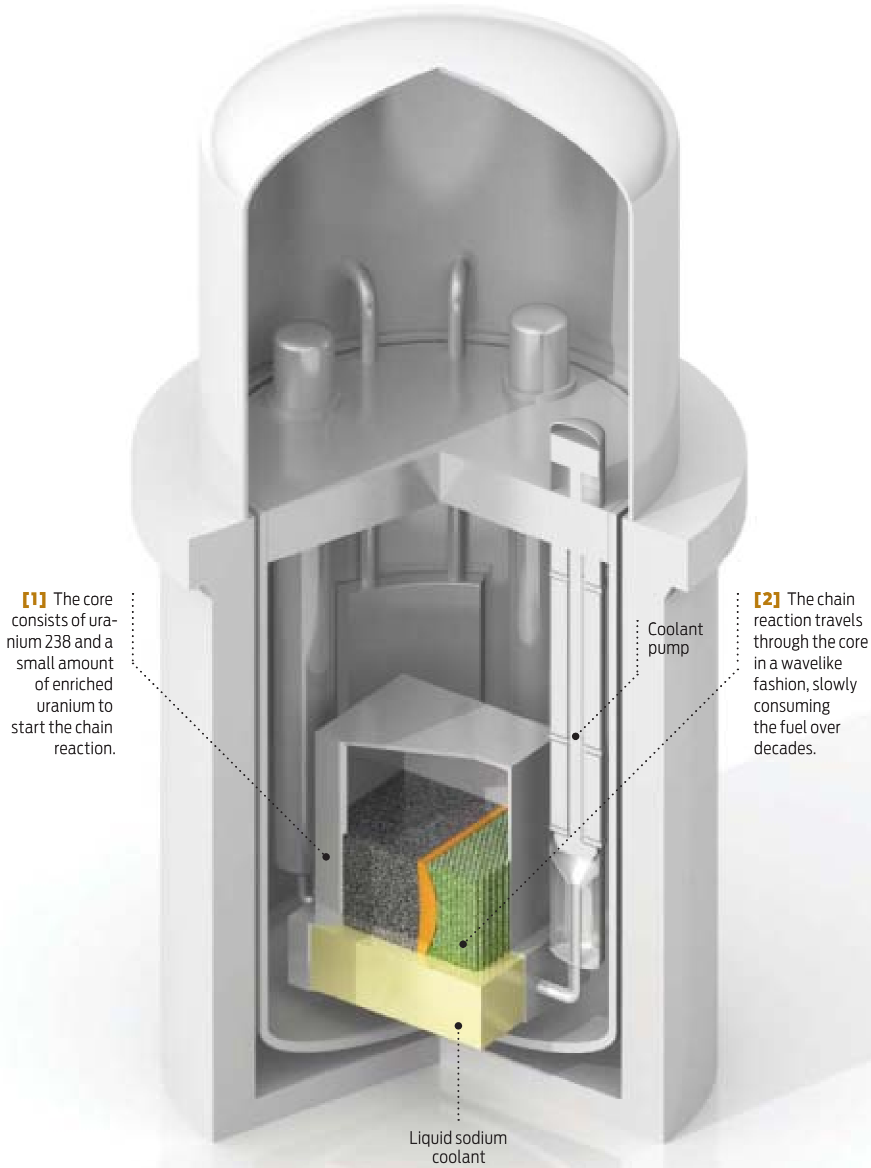


# TERRAPOWER TP-1

This reactor produces a nuclear reaction wave that breeds and burns its own fuel—and lasts for decades

**MANUFACTURER:** *Intellectual Ventures*

**HQ:** *Bellevue, Wash.*

**TYPE:** *Traveling-wave reactor*

**POWER:** *Thermal, 900 to 1250 MW; electric, 350 to 500 MW. Designed as a modular reactor that can be combined into larger gigawatt-scale plants*

**FUEL:** *The main fuel is depleted uranium, which can be found as uranium hexafluoride, a by-product of the uranium enrichment that is a part of current fuel production. (The reactor can also use spent fuel from light-water reactors.) The uranium 238 is transformed into uranium metal-alloy fuel and placed into rods that will form the core. The core needs an "igniter" consisting of enriched uranium (10 to 12 percent of fissile uranium 235); the igniter represents a relatively low percentage of the core's weight.*

**REFUELING:** *The reactor takes 40 to 50 years to consume fuel; no refueling is necessary during this period, but shuffling fuel rods to improve the burn-up rate might be required.*

**COOLANT:** *Liquid sodium, which flows along the length of the fuel rods. Boron carbide control rods are placed within the current position of the wave, at locations where they can control power and reactivity.*

**MODERATOR:** *No moderator (it's a fast reactor)*

**WASTE:** *Leftover uranium fuel, excess plutonium, and other high-level radioactive waste. Waste can remain in place after reactor is decommissioned.*

## HOW IT WORKS:

A core vessel in the shape of a cylinder or parallelepiped is filled with mostly uranium 238, except for a relatively small amount of enriched uranium—the igniter—which is placed at one end of the vessel **[1]**. The igniter produces an initial flow of neutrons, which unleash a nuclear chain reaction. Because of the geometry of the vessel and the atomic properties of the uranium, the chain reaction travels through the core in a wavelike fashion, moving at a rate of a few centimeters per year and consuming the fuel from one end to the other, like the ember of a burning cigarette **[2]**. The wave consists of two reactions: The first breeds uranium 238 into plutonium 239; the other fissions the plutonium, producing more neutrons and heat. No new fissile material has to be added once the wave has started. If necessary, the reactor can be shut down using control rods; when the rods are removed, the wave naturally restarts.

## ADVANTAGES:

The reactor doesn't require enrichment or reprocessing, thereby reducing proliferation risks. It uses depleted uranium as fuel—a by-product of uranium enrichment that exists in large quantities and is unused. (It can also use spent fuel from existing light-water reactors.) One fuel load lasts for several decades, so the reactor can be sealed and won't require refueling. Waste can remain in place after the reactor is decommissioned. A "mother reactor" could be used to start a breed-and-burn wave in a core, which is then shut down, transported to another location, and restarted there. The nuclear physics of the traveling wave has been extensively simulated in advanced computer models.

## DISADVANTAGES:

The design has not been fully tested. It would also depend on fast-reactor systems and materials that have not been used commercially. To start the wave, the reactor would need several tons of uranium enriched to about 10 percent, or almost double the enrichment level of light-water-reactor fuel. It would produce many tons of excess plutonium and other high-level radioactive wastes. The reactor has a high power density—a few hundred megawatts per cubic meter, compared to about 100 megawatts per cubic meter for a standard LWR—and would require liquid metal as coolant and cladding materials that have yet to demonstrate resistance to very-long-term heat and neutron exposure. Building and operating the first reactor would require cooperation from multiple entities and political support.

## TIME FRAME:

The project started in 2006. TerraPower will seek international cooperation to construct and operate the first reactor. The company expects to have a test reactor operational in 2020 and to push the technology to commercial scale in the late 2020s.

# Home, Smart Home

**A Danish experiment field-tests a sentient, carbon-neutral house for the masses**

BY ELLEN KATHRINE HANSEN



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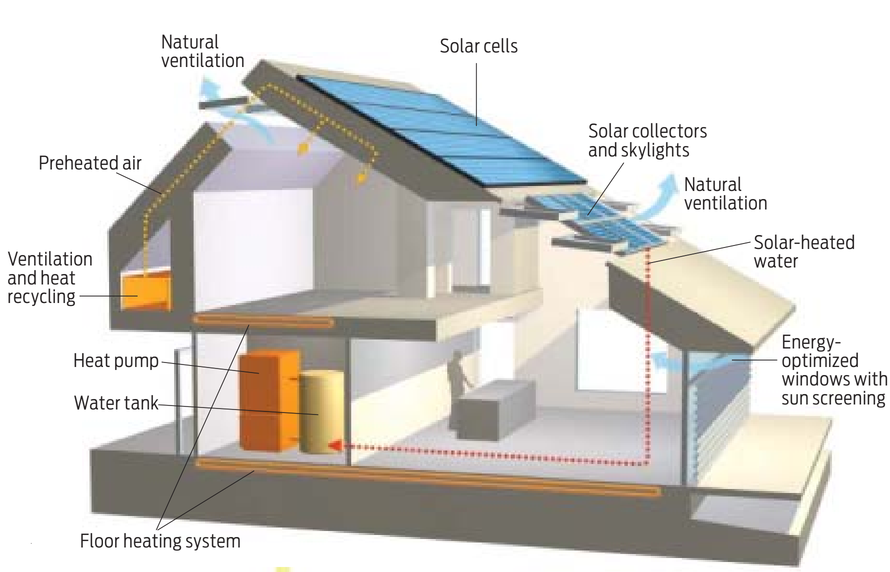
**JUDGING BY LOOKS ALONE,** you'd never guess that the simple one-and-a-half-story house on a residential street outside Århus, Denmark, is anything more than an ordinary single-family home. The stylish little house has the broad windows and long sloping roof of a typical Scandinavian home; a trampoline sits on the neatly trimmed lawn.

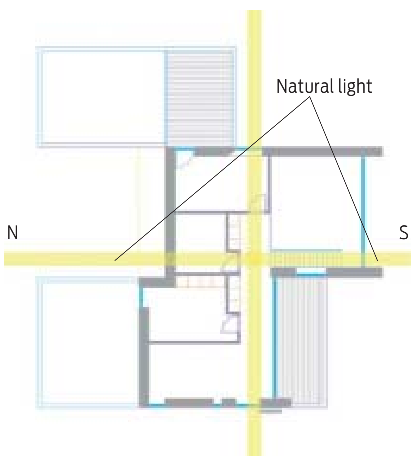
But this house is different. Using ecologically benign materials, a rooftop of solar panels, and energy-scrimping designs, the house generates more than enough power to run itself.

Inside, a family of five is testing out the ultimate model home. Windows in all four walls and a slanted skylight flood the first floor with sunshine. Built-in blinds twitch autonomously to adjust to the glare, angling their slats just so. To bring in more fresh air, the skylight slides open with a hiss. "It's fun to listen to," the children report.

The family is now nearing the end of its 14-month sojourn in the Home for Life, the first prototype of a Danish concept known as an "Active House." At this point they no longer really notice the house's impressive array of technologies or its subtle machinations as it works to secure their comfort. Specialized windows, tight insulation, and a climate-control system minimize the need for electricity and heating. The sun handles the rest: Solar panels, solar thermal collectors, and the Home for Life's south-facing orientation allow the house to generate enough electricity and heat to make it carbon neutral. What's more, the use of building materials that can be produced with less energy means that the emissions from their manufacturing will be canceled out in about 40 years.

As the lead architect and project manager on this house, I worked closely with engineers, architects, and window specialists to make sure that every design decision took the energy plan into consideration and that every technical requirement was framed in terms of




**HOW IT WORKS:** The south-facing roof surface hosts an array of technologies that allow the house to produce heating and electricity from sunlight. The deliberate placement of doors and windows creates a "light cross" that floods the first floor with natural light.

aesthetics and comfort. What we came up with is a design that unites low-tech and high-tech elements. Because we've never done anything like this before, we're treating it like an experiment, including a test family to help us investigate our theories.

The house is the first of eight experiments that the company I work for, VKR Holding, based in Hørsholm, Denmark, is financing in five European countries. The goal is to reinvent the home—to build a sustainable, affordable house that uses readily available technology to negate its imprint on the environment and to promote the health and comfort of its inhabitants. Our first prototype cost about US $700 000 to build, not including the design and planning. In July 2009, the Simonsen family moved in.

And so the experiment began.

**GRANTED,** it's a little funny to be watched and studied this way—even by a professional anthropologist," wrote Sophie and Sverre Simonsen in their online diary last September. The Simonsens had lived in the house for 3 months, and it was already abundantly clear that this was going to be an unusual year.

An anthropologist had asked the young parents to map their movements through the house. We'd designed the core of the house as a "light cross," which cuts through the 40 square meters that make up the kitchen and dining area and the living room, and we wanted to know if this design worked for the family. To minimize the need for artificial lighting, we designed the space so that daylight pours in from all four points of the cross, which also serve as exits, ventilation openings, seating recesses, and frames around a view. The family's records showed that they were indeed content to spend the bulk of their time in the light cross.

We needed the Simonsens' reflections because the raw data tell an incomplete story. Just looking at the numbers, the summer months were spectacular: The house generated 800 kilowatt-hours of electricity last August, used just a bit more than half of it, and fed the rest back to the grid. But did the family actually enjoy living here? We were curious whether they were sick less often or missed fewer days of work—or not. Our test family has helped us decipher where we've succeeded and where we still have work to do.

The rationale for this holistic approach to architecture is straightforward. Many modern buildings are toxic, and they consume way too much energy. We estimate that about a third of buildings today have an unhealthy indoor climate, which can exacerbate allergies and asthma, affect a person's ability to concentrate, and even trigger depression. The built environment is also a significant energy burden—around 40 percent of an industrialized country's energy goes to its buildings. That's not surprising when you consider that we spend around 90 percent of our time indoors. But it doesn't have to be that way. One of the goals of VKR Holding, which has invested in several companies dedicated to improving the internal environments of homes, is to start turning some of those numbers around.

There are a few ways to do this. One approach is to design houses with small windows and thick walls filled with insulation; this strategy prevents the sun from overheating the interior, cuts down on air-conditioning in the summer, and reduces heat loss in the winter. But it doesn't make for a delightful living experience. The people living in one such house complained to me that it was so heavily insulated you couldn't even hear birds singing outside.

So we decided to build a house that didn't wall itself off like a fortress from the sun but instead invited sunlight and fresh air in. In a word, that means windows. Our test house has about double the window area of an ordinary Danish house. We chose specialized panes with two or three layers of glazing, which in the cooler months reduces the heat escaping from the inside while allowing lots of heat and daylight to enter. In fact, the windows alone deliver half of the heating needed in the winter.

The windows' frames also add insulation. They're made of a brand-new type of polyurethane (the stuff that foam is made of) strengthened with thin glass threads. Engineers at Velfac, a VKR subsidiary, tested more than 200 materials before finding one that was at once highly insulating and durable and had a pleasing surface finish. Because of the material's strength, a weather-resistant frame can be made with just a slim sheet of this polyurethane.

The large windows cut down on the amount of indoor lighting and mechanical ventilation needed—good news for our net-zero-energy goal. But sometimes we need to keep the interior heating in check. To do so, a roof overhang on the south side provides shade when the sun is high in the summer, and shutters and blinds on both sides of each window reg-

PREVIOUS PAGES: ADAM MØRK; THIS PAGE: GEORGE RETSECK

**THE INTERIOR:** A touch-screen computer display lets the family observe the house's energy performance and adjust the internal climate controls. In the kitchen, skylights slide open automatically to let in fresh air. Window blinds self-adjust to reduce glare from the sun.

**THE EXTERIOR:** Solar panels that produce electricity, solar collectors that capture heat, and skylights vie for space on the house's Scandinavian-style slanted roof. The facades and roof were built out of wood and slate, which require less energy to produce than other commonly used materials.

CLOCKWISE FROM TOP LEFT: MORTEN FAUERBY FOTOGRAFI; MICHAEL FRANKE; ADAM MØRK (2); MARTIN DYRLØV MADSEN (2); ADAM MØRK

ulate the transmittance of heat and provide privacy.

To further reduce the risk of overheating, we programmed the windows to open on their own to let in fresh air. Sensors in every room track the temperature, carbon dioxide levels, and humidity, and a weather station on the roof monitors outside conditions. Our control system, from another VKR company, WindowMaster, uses that information to decide when to lower the solar screens or slide open selected panes. These automated adjustments of the windows, rather than traditional air-conditioning and heating, provide the bulk of the house's temperature control.

Unfortunately, the settings we chose didn't always agree with the Simonsens. As the parents reported, "The windows are open even though we feel cold. There is a draft, so we wrap ourselves in blankets and close the windows with the remote control...but alas, half an hour later they open automatically again!"

It took several months for the family to adjust to their Active House. On first entering, a casual observer might be taken aback by the house's autonomy. The sound of the shutters adjusting or a window sliding open can make the house seem eerily sentient. One of the challenges we faced was balancing the need



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for precise control to keep the energy demand low with the desire to hide the engineering from the inhabitants.

Sophie jotted down her reactions as the family slowly became comfortable with its animated home. Some of the house's peculiar habits persisted, though; the lights, for instance, would switch off unexpectedly, even when a room was occupied. "I rocked back and forth in the chair to ensure that the light did not go off," she wrote. "It gives a whole new meaning to 'Active House,' but from outside it probably looked pretty crazy."

**SO HOW DO YOU** power a self-governing house?

In total, the Home for Life ought to use about 60 percent of the energy of a traditional single-family house in Denmark: 15 kWh per square meter per year for lighting, household appliances, and running the active components of the house and 32 kWh/m² per year for hot water and heating. It's the latter where the Home for Life really stands out: Its heating consumption is just half that of an ordinary Danish home. Once all the systems are fine-tuned, we estimate that the house will generate a surplus of about 9 kWh/m² per year.

The shape of the house made a big difference. Its overall surface area was kept to a minimum because that is a major factor in heat loss. In addition, the tip of the roof is tilted to the north, which increases its surface facing south. That side of the roof is covered with solar panels, solar thermal collectors, and skylights, each of which plays an important part in determining the house's overall energy budget.

First, let's look at the electricity. The 50 m² of polycrystalline solar panels generate about 5500 kWh a year. That's 20 percent more electricity than the house needs, although in winter it does draw some power from the electricity grid. These solar cells, with 13 percent efficiency, aren't the best on the market, but they're a good compromise for the price.

Then there's the heating, which comes in through the windows or the solar thermal collectors. The 6.7 m² of collectors catch the sun's rays on copper plates installed on the lowest part of the roof. Underneath the plates, copper pipes circulate a fluid that absorbs the heat of the plates, converting 95 percent of the sun's energy into heat. The collectors can catch indirect sunlight, too, so the house still has heat on cloudy days.

Should more interior heating be needed, we use an air-source heat pump. In one common configuration of this type of pump, air passes through a heat exchanger placed outside the house to transfer the air's warmth to a liquid. The liquid travels to an electrically powered compressor inside the house, which applies pressure to raise the fluid's temperature further. In general, a heat pump is far more energy efficient than conventional oil or electric heating, and it has lower $CO_2$ emissions, too. But the pump's performance depends

**FAMILY PHOTO:** The Simonsens came to love their sentient home and its environmentally sound design.

heavily on the amount of heat contained in the air; when it's cold outside, these heat pumps aren't efficient.

To avoid that problem, we used a heat pump designed by another VKR subsidiary, Sonnenkraft, which uses the solar collectors to preheat the cold winter air before it reaches the heat pump. The pump can now easily produce 20 °C water even when the outside air is below freezing. After the liquid is compressed, the heat travels through pipes in the floors and to radiators. In all, our solar collectors and pump can produce about 8000 kWh's worth of heat a year.

Generating power and heat was only part of our design goal, though. Equally important to us was the wish to pay off the energy invested in the materials. To meet that challenge, we chose materials that require less energy to produce. We used wood for most of the construction, with a few steel beams added for load-bearing parts of the structure. We made the facades and roof out of natural slate rather than brick, which has a larger energy footprint.

**OUR CAREFUL INNOVATIONS** and calculations didn't always line up with the family's preferences, however. As the weather grew colder, the Simonsens complained that they weren't warm enough. We ended up raising the temperature of the heating under the floors by 2 degrees, and we stopped lowering the room temperatures at night.

The net result was, of course, an increased energy load. Fortunately, we'd overestimated how much electricity the Simonsens would use for lighting and appliances, so we reduced our estimates for those activities from 3.5 watts per square meter to 2 W/m². Then again, they sometimes kept the blinds drawn during the day—for privacy and to reduce glare—which lowered the amount of radiation available to heat the house.

In time, though, we think the Simonsens would have kept the blinds open more as they grew to understand how the windows affected their energy consumption. We know the family recognized the house's energy performance and is proud of it. On one particularly bright day, Sverre examined the computer display in the hallway that charts the house's energy performance, and the power of the sun truly hit home. "It was obvious here on Sunday when the sun came out," he wrote in the family's diary. "I just had to go and check: Was it really affecting energy output? Yes it was! That was a real 'ta-da!' moment."

We plan to share all these observations and data with the world in a new set of metrics we're now drafting, which encompass not only theoretical energy consumption but also the environmental impact and the inhabitants' well-being. We've also begun the next three Active House experiments: Green Lighthouse, a round building on the University of Copenhagen campus, as well as two single-family homes in Austria and Germany.

The Simonsens will be moving out of the house in one month, and the Home for Life will go on the market. If the family's satisfaction is any indication, we're well on our way to proving that environmentally friendly, carbon-neutral homes make for happy, satisfied inhabitants. ❑

MICHAEL FRANKE



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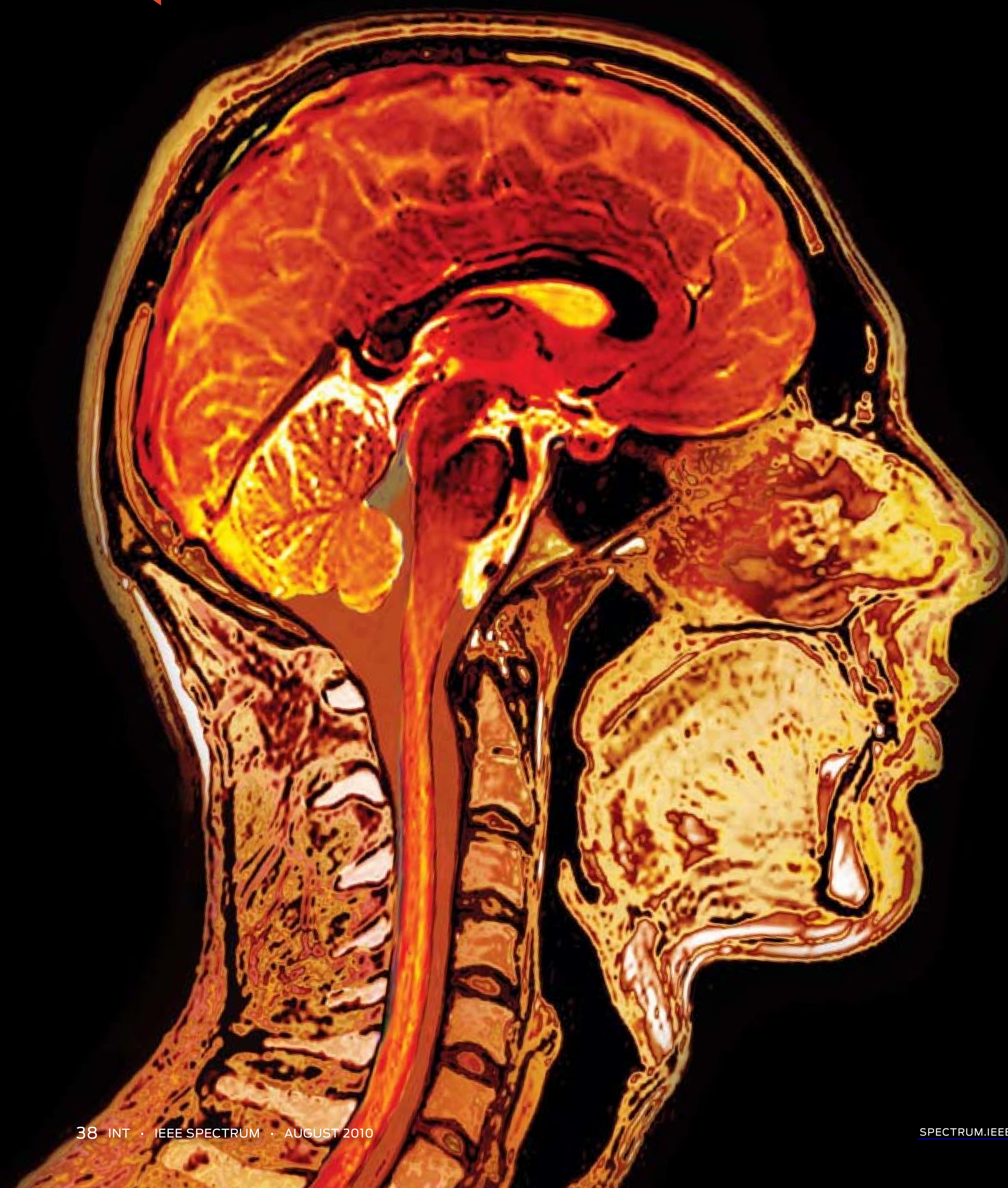
# LIAR!

## Can brain scans show whether people are telling the truth?

*By* MARK HARRIS





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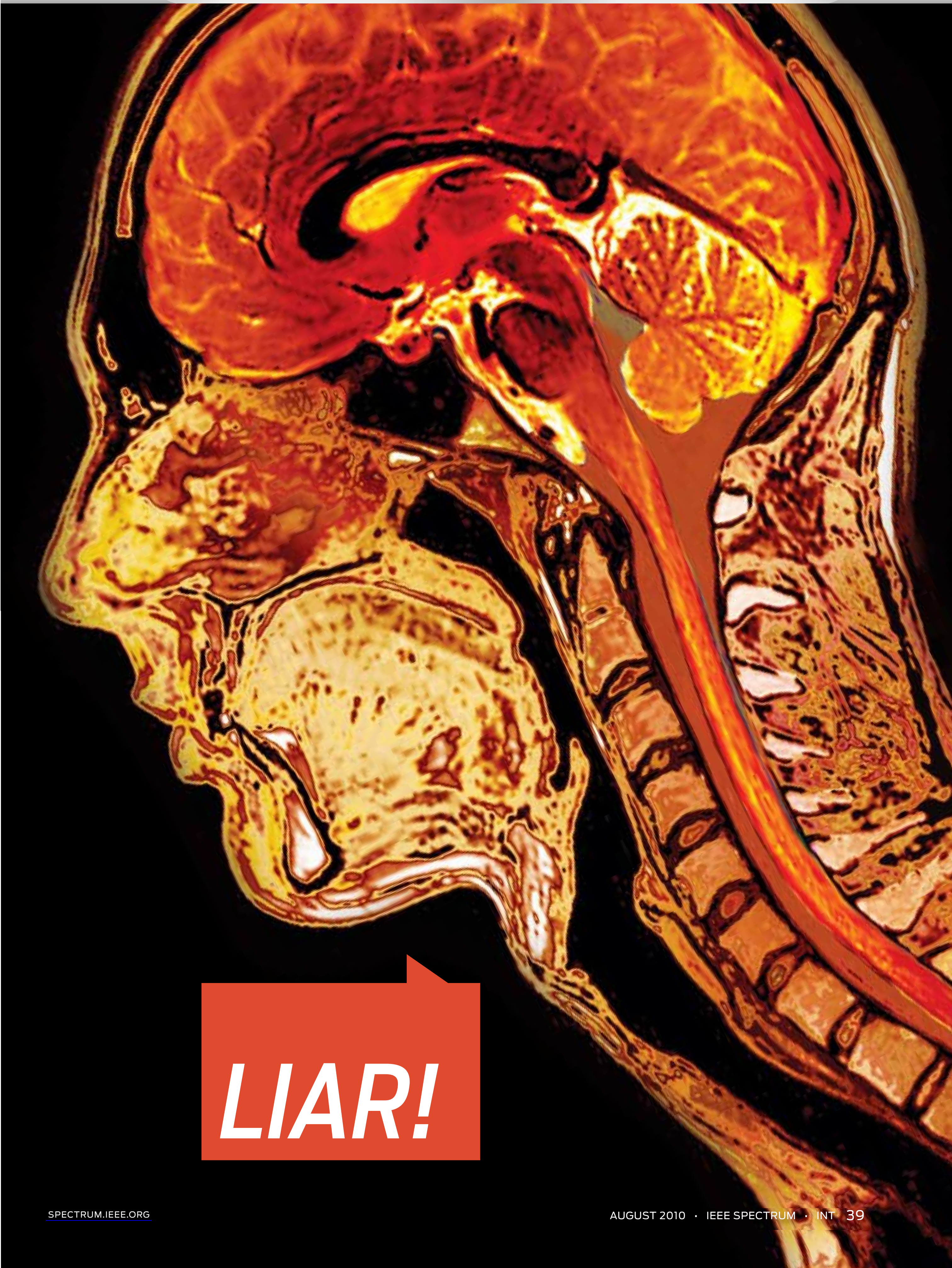




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# *Nervously, my heart pounding,*

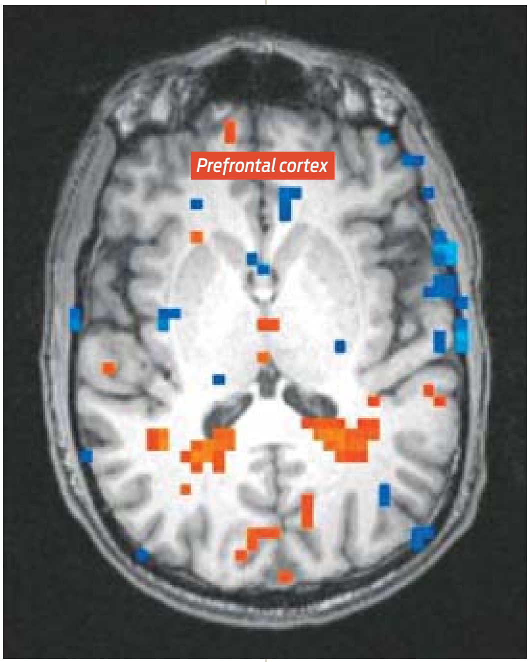
I remove my clothing, watch, and wedding ring. No, it's not an extramarital tryst. The only affair I'm involved in is reporting on a new form of lie detector, one that uses magnetic resonance imaging (MRI). That explains the need to shed my clothes, which might have magnetizable metal parts in them, along with the watch and ring, which could be sucked with dangerous force into the powerful magnet of the apparatus. (Accidents from flying metal have injured and even killed MRI subjects in the past.) I then don hospital garb and climb onto a platform that glides me into the heart of an impressively large if somewhat cramped scanner.

I'm here to investigate No Lie MRI, a San Diego company that is offering US $5000 "truth-verification" sessions. Around my head, a superconducting electromagnet cooled to within a few degrees of absolute zero generates a magnetic field that's about 50 000 times as strong as Earth's.

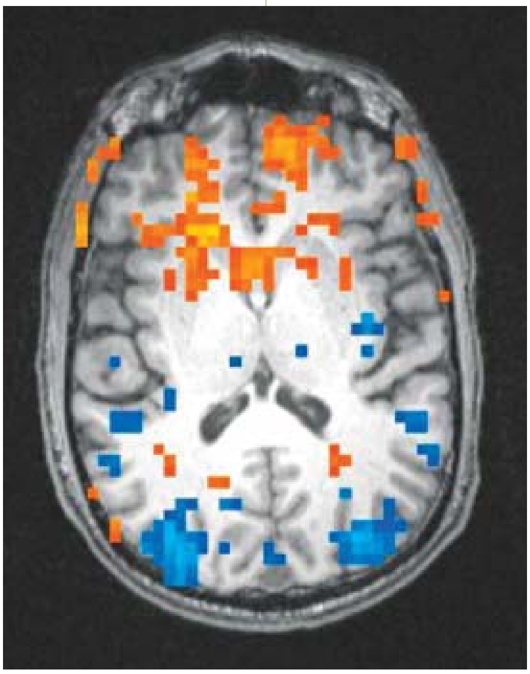
To the accompaniment of various clicks and clacks, a screen above my head flashes a series of questions in front of my eyes. Did I ever claim more than I should have for business expenses? Have I cheated on my wife? Have I pretended to be ill in the last year? I am tested on nine questions in all. The topics are serious enough to provoke strong emotional responses but innocent enough to save No Lie MRI from having to report me to the authorities should I appear to be covering something up. I had settled on the questions with the company beforehand and promised to provide truthful answers to all but one of them, giving No Lie MRI an 11 percent possibility of spotting my fib by chance alone.

While I'm in the machine, the questions arrive at unpredictable intervals and are repeated several times throughout the session. Control questions are shuffled in at random. After 10 minutes, my grilling is over, and the complex business of analyzing the data begins, a process that will take several days. I've done my best to deceive my interrogators, and they will do their best to read my mind.

No one is suggesting that such elaborate tests are suitable for petty criminal cases or regular employee screenings—especially at $5000 a pop. And the courts are far from accepting the results of such scans as evidence. But that hasn't stopped lots of people from putting their money where their brain waves are. No Lie MRI's clients include a store owner who wanted to prove that he did not commit arson for the insurance payout, a woman trying to convince her husband that she hadn't been unfaithful, and a father denying allegations of child abuse.




**THE TRUTH BE TOLD?** When the author was asked whether he had ever feigned illness to escape an obligation, his prefrontal cortex showed no unusual activity.



**LIAR, LIAR?** When the author was asked whether he had ever padded an expense report, his prefrontal cortex became highly active [areas highlighted with hot colors].

PREVIOUS PAGES: ISM/PHOTOTAKE; THIS PAGE: NO LIE MRI

Could this really work? A machine that could reliably separate truth from lies would be a police detective's dream—and a civil libertarian's nightmare. Your opinion may depend on which side of the device you're on, but many people would like nothing better than having a truly foolproof lie detector. All that's been available in the past has been the polygraph—a cobbled-together battery of sensors that monitor the subject's pulse, sweating, and breathing rate. Polygraph testing is error prone, and experts struggle even to quantify its level of reliability.

One reason for that struggle is that the interpretation of a polygraph's measurements is unavoidably subjective. Set the detection threshold low enough and you'll net almost any liar. But you'll also falsely identify many truth tellers. Laboratory studies of polygraph testing show that when you set the threshold so that the false positive rate is a troublingly high 30 percent, you'll still detect lies only between 64 and 100 percent of the time. That's a wide range, and the low end reflects rather poor performance for a lie detector. Also, experts generally agree that polygraph testing probably works worse in the real world than it does in the lab, though how much worse isn't clear.

For these reasons, the U.S. National Academy of Sciences was somewhat vague in its overall assessment of polygraphs, saying that these machines could (at best) discriminate lies from the truth at rates "well above chance, though well below perfection" and remain "an unacceptable choice for security screening." No wonder the U.S. legal system has never fully embraced this technology. In most other parts of the world, the courts, law enforcement, and even the business community just scoff at it.

So now we have a new breed of lie detector, based on MRI, that promises to do away with using unreliable physiological responses to reveal a person's innermost thoughts. With the help of multimillion-dollar scanners, sophisticated pattern-matching algorithms, and cutting-edge neuroscience, you can now detect the hardwired patterns in the brain that indicate deception—or at least that's what supporters claim. I was determined to find out for myself whether this was true, even if I had to 'fess up to some personal foibles to do it.

*The mechanism in your brain is the same* regardless of whether you tell a big lie or a little lie," says Joel Huizenga, chief executive officer of No Lie MRI. "It doesn't matter whether you feel guilty or not, it doesn't matter if you've memorized your story, and it doesn't matter whether you believe your lie would save the world. We can still spot it." Huizenga foresees a day when philanthropic foundations won't hand over funds to charities and venture capitalists won't invest in start-ups unless the prospective recipients pass an MRI brain scan for honesty.

The only other company now offering commercial MRI lie detection, Cephos Corp., based in Tyngsboro, Mass., grew out of academic research done at the Medical University of South Carolina. That research was funded in part by the Department of Defense's Defense Academy for Credibility Assessment, the agency that oversees federal polygraph training. "We've done really good work that has been published and peer reviewed," says Cephos president Steven Laken, a Ph.D. neuroscientist. "We have something that's 97 percent accurate."

It's no great surprise that modern technology should be able to supplant traditional polygraph testing, which was first developed a century ago. What's remarkable, though, is that no one has actually set about to design a new lie detector. But some have found the makings of one in the now-ubiquitous MRI scanner.

*Because nerve cells require more oxygenated blood when they're busy processing information, an appropriately configured brain scan can trace the locus of mental activity*

Since the 1980s, physicians have been using MRI scanners to diagnose disorders of soft tissues. These machines work by placing the portion of the body to be scanned within a powerful magnetic field. Weaker fields are then applied rapidly at angles to the main field, causing hydrogen nuclei within body tissues (mostly in water and fat molecules) to resonate and emit faint electromagnetic signals. The detailed characteristics of those signals depend on the position as well as the physical and chemical environment around the emitting nuclei. The data collected with an MRI scanner can thus be assembled into 3-D images that permit doctors to spot many sorts of abnormalities without requiring invasive procedures.

Scientists soon realized that MRI technology also provides a way to chart the functioning of certain organs. The trick is to make faster, less precise scans, which give rapid-fire snapshots of the body's dynamic functioning, a methodology that became known as functional MRI, or fMRI for short.

One of the things that can be tracked with fMRI is how oxygenated the blood is in a particular area. That's because the magnetic properties of hemoglobin, the oxygen-carrying molecule in blood, depend on how much oxygen it has on board. And because the nerve cells of the brain require a greater quantity of oxygenated blood when they're busy processing information, an appropriately configured fMRI brain scan can trace the locus of mental activity.

This technique was pioneered in the early 1990s, and once it was developed, psychologists became very interested in what it might show. Was it possible to correlate areas of increased brain activity with particular mental and emotional states? Could MRI scanners gather information not just about the brain but also about the mind itself? Neuroscientists were still debating these issues when some researchers, including Daniel Langleben at the University of Pennsylvania and

Sean Spence at the University of Sheffield, in England, began fMRI experiments in the early 2000s focused on revealing brain states associated with deception.

Their efforts to use fMRI to detect lies relied on a technique called cognitive subtraction. The idea is that when a person tells the truth about something, many parts of his or her brain may become active. For example, if somebody shares with you that he likes colorful clothing, certain parts of his brain would have to shape that thought and the expression of it. Now, let's say that same person tells a lie—perhaps that he loves your new yellow-and-purple-plaid golf pants. In this case, the same parts of his brain would presumably go to work, but there would be additional activity in other regions, too, perhaps those involved with inhibiting the chuckle he might be making to himself about your garish attire.

If an fMRI brain scan were performed in both instances—truth-telling and lying—the difference between the two scans would highlight certain areas of the brain. If you carried out similar fMRI measurements on a large number of people, you might be able to identify the brain's deception centers. Detecting brain activity in those regions with an fMRI scanner would then, in theory, provide a way to tell when someone is being dishonest.

One shortcoming of this approach is that it hinges on the assumption that everyone's brain works the same way. But another strategy that's sometimes applied doesn't depend so much on all of us being wired alike: You ask the subject in your fMRI scanner to provide both truthful and deceptive answers to a series of test questions, knowing which are truths and which are falsehoods. A computer can then train itself automatically to recognize what may be a complex and completely unique pattern of brain activity that occurs when this particular person lies.

Laboratory tests of both these approaches appeared promising, and by 2008, 16 peer-reviewed papers on the subject had been published. Most of them indicated that when people are lying, there is more activity in certain parts of the prefrontal cortex, the area of the brain thought to be involved in orchestrating a person's thoughts and actions. And most of those studies reported no areas of the brain where activity was greater when someone told the truth.

This was just the boost Huizenga and Laken needed to launch their businesses. No Lie MRI acquired the patent rights to Langleben's specific methodology and set up shop. Cephos used a different variation of cognitive-subtraction technique to do the same. Because both operations grew out of academic research projects, experts can scrutinize the methodology being applied and argue about its merits. And argue they do.

"I doubt that there is any large group of neuroscientists that would say single-subject fMRI analysis is useful for lie detection," says Gary Glover, a professor of radiology, neurosciences, and biophysics at Stanford University's School of Medicine. "The way that cognitive neuroscience works is that you scan 30 or 40 people, look for average results, and then publish those. The reason for doing this is that people vary quite a bit: One person's anecdotal result may not hold for the population in general or for any other person."

> *"We're making progress, but there's a catch-22. Prosecutors aren't supposed to prosecute when they don't think a person is guilty, so if we come to the table and really convince them, then they don't prosecute"*
>
> *Joel Huizenga*, CEO, No Lie MRI

Moreover, argues Glover, the basic fMRI technique is unlikely to become more accurate with time. "It's about as good as it's going to get," he says. He doesn't deny that MRI technology might improve, but he thinks that variations in human physiology will fundamentally limit an interrogator's ability to detect changing cognitive states. That's why Glover believes much more research would be needed to demonstrate that the vague and fundamentally ambiguous signals fMRI generates could provide an adequate basis for a commercial lie-detection service.

Although he helped to pioneer fMRI lie detection, Spence shares Glover's skepticism. "Certain central problems remain, not least the absence of replication by investigators of their own key findings. Further data are required to justify its application to the field of lie detection," he concludes.

Researchers' doubts notwithstanding, Cephos is working hard to introduce fMRI lie detection to the American legal system. The company's most recent effort involves a Tennessee psychologist who was accused of submitting false insurance claims. His attorneys tried to offer as evidence tests that Cephos performed in an attempt to show that he genuinely had no intent to commit fraud. Awkwardly for the defense, it came out during the trial that one scan Cephos had made of the psychologist indicated that he was lying. The company later repeated that same test, and the new results showed him to be telling the truth. Prosecutors, reasonably enough, objected to the do-over, and this past June the Tennessee court declared the fMRI results to be inadmissible, mostly because the method hasn't received any scientific real-world testing.

No Lie MRI has been no more successful in getting its results accepted as evidence in a court of law. "We're making progress, but there's a catch-22," Huizenga complains. "Prosecutors aren't supposed to prosecute when they don't think a person is guilty, so if we come to the table and really convince them, then they don't prosecute."

In November 2009, MRI brain scans were used in court for the first time, in an application that had nothing to do with lie detection. During a sentencing hearing in Illinois for the convicted multiple murderer Brian Dugan, defense attorneys used MRI scans that showed Dugan had abnormal brain functioning. Laken thinks that marks the beginning of a trend. "We're on track," he says. "In one of our cases, the judge made a number of favorable comments and said that she would seriously consider the technology. She admitted the technology as evidence but didn't use it to make a ruling. These are cracks in the glass."

Hank Greely, director of the Center for Law and Bioscience at Stanford Law School, is doing his best to stop those cracks from spreading. "Judges, jurors, all of us, we've got this longing for a magic tool that will tell us whether someone is lying or telling the truth," he says. "But we have to be very cautious about thinking it's here because we want it to be here. I haven't seen anything today that leads me to believe fMRI is better than polygraphs. If we start using a bad technology, people's lives are going to be hurt—not just innocent people who are falsely convicted but guilty people who are falsely exonerated and go on to ruin the lives of other people."

Greely, who is a lawyer by training, believes that much more research is necessary. He is involved in some of the research himself and recently coauthored a report on the use of fMRI to determine whether a subject has recognized a particular face. Although the study indicated that fMRI could reliably show whether the subject *thought* he or she recognized a face, it couldn't tell you whether the subject had truly seen that face before. This suggests that fMRI wouldn't help in distinguishing false memories from true ones.

"Experiments are hard to design, but until we get more realistic studies, there's no proof that what happens in the lab is relevant to what happens in the real world," Greely says. Unfortunately, the studies needed to evaluate the reliability of fMRI lie detection in real-world situations would be extremely expensive. A five-year study covering a range of ages, languages, and cultures would run about $125 million, Greely estimates.

The one group that could afford to fund research on such a scale is not renowned for sharing its findings with scientists, lawyers, or businesses. "I know that DARPA [the Defense Advanced Research Projects Agency] has funded quite a lot of research in this area—and maybe other Department of Defense agencies for obvious interests that they might have," says Glover. "This research is pretty much under cover of night. I happen to know about a few studies, but I would have to shoot you if I told you."

Occasionally, evidence of the military's interest in fMRI does see the light of day. For example, in 2006, DARPA solicited proposals for research to "understand and optimize brain functions during learning" using fMRI technology, followed a year later by requests for a transportable battlefield MRI scanner.

"For the intelligence community, what we're interested in are going to be devices that you can use remotely," says Sujeeta Bhatt, a research scientist with the Defense Intelligence Agency. "We can create a fantastic map of deception in fMRI, but what we use for national security has to be something that we can train anyone to use fairly easily, that's fairly portable, and not outrageously expensive."

Such a device won't use fMRI, Bhatt believes. "Functional MRI has serious limitations. Countermeasures haven't been seriously studied, but of the ones that have, simply moving your tongue can compromise the data," she says. "And in the intelligence community, the people that you're screening have really studied their cover stories. Will that look like truth or a lie? We're not there yet, and in terms of using [fMRI] as a practical, everyday tool to detect human deception, I don't think we're ever going to be there."

Huizenga contends that others in the military are right now seeking the know-how his company offers. "We are dealing with the military. The guys in the field are asking for this technology. They want to know whether people are telling them the truth or telling them lies." He refuses to provide any specifics, other than saying that No Lie MRI hopes shortly to secure government funding for a multimillion-dollar, 1200-person study. If such a large study is actually carried out, it could well determine the future of fMRI lie detection.

*God knows what the intelligence community,* the CIA, and MI6 are spending on this work," says Greely. "All the studies are secret, and science doesn't work well in secrecy." It appears not to work all that well in San Diego, either, judging by the results of my own interrogation in the scanner.

According to No Lie MRI, when I denied that I misstated business expenses, the region of my prefrontal cortex associated with deception lit up like a Christmas tree. For the record, I never pad expense reports (note to editor: honest!).

On the other hand, when I claimed that I had not feigned illness to weasel out of an obligation, there was nothing going on out of the ordinary in my frontal cortex, and only two spots elsewhere in my brain became active, providing no evidence of deception. In fact, I have many times claimed, falsely, that I didn't feel well enough to take on a household chore or attend what I expected to be a dreary party.

Huizenga cautions me not to imagine this means I would make a great con man. "In a real test, we make all the questions virtually identical, allowing us to compare your answers against known truths," he says. Perhaps so. But if fMRI lie detection is ever to break out of its academic ghetto and storm the courtroom, boardroom, or battlefield, it will have to succeed in precisely those situations where the absolute truth is not known. And you don't need to be a mind reader to see that that day is still a long way off. ❑

# On 1 June 2009, Air France Flight 447, an Airbus A330-200, crashed into the Atlantic Ocean, killing all 216 passengers and 12 crew members. No one knows why the plane fell out of the sky, because no one has ever found its black box.

## BEYOND THE BLACK BOX

Instead of storing flight data on board, aircraft could easily send the information in real time to the ground

BY KRISHNA M. KAVI

VIKTOR KOEN

The plane plunged so deep that the black box's sonar beacon could not be heard, and by the time the French navy had dispatched a submarine to the area, the beacon's battery had evidently died. Crash analysts were thus reduced to poring over information the airliner had transmitted before going silent, information too sparse to determine what had happened, let alone how to prevent it from happening on some other airliner.

For half a century, every commercial airplane in the world has been equipped with one of these rugged, reinforced, waterproof boxes, which each house a flight data recorder and a cockpit voice recorder. For hundreds of crashes, they have given investigators the often heartbreaking details of the plane's demise: the pilot's frantic last words, his second-by-second struggles to keep the plane airborne, and the readings of the gauges and sensors that reveal such key parameters as the airspeed, altitude, and the state of the plane's engines and flight-control surfaces. Such information has enabled analysts to infer the causes of most crashes and, often, to come up with preventive measures that have saved thousands of lives.

Every now and then, though, a black box is destroyed, lost beyond all chance of recovery or, as in the case of Air France 447, beyond all chance of detection. Lacking the black box and its precious data, we have no way to tell whether the last problem reported was the cause of the crash, the result of a deeper problem, or just an artifact of the sensor system on board. And because we can't pinpoint the cause of the crash, we can take no steps to prevent similar failures in the future.

The black box may be the greatest single invention in the history of safety engineering. Nevertheless, technology has moved on, and we can—we must—improve on it. Rather than store data in an onboard box that might be unrecoverable if the aircraft goes down in the sea, it would be far better to transmit the data continuously and in real time to a ground-based system that would record the output of the plane's sensors and electronics. In the event of unusual behavior, such a system could even automatically request additional information. It could also preserve data from many aircraft, over many flights and many years, and mine this information with sophisticated algorithms to identify the signs of recurring problems.

I ENVISAGE A GLASS BOX, that is, a system that would be transparent because it would be in the cloud—not a cottony puff in the sky but rather the network of servers and databases that covers ever more of the world every day. The system would offer ubiquity, invulnerability, unlimited storage, and unparalleled powers of search.

Consider how the glass box might have been of use in the more recent incident of Northwest Flight 188. While en route to Minneapolis from San Diego on 21 October 2009, it flew past its intended destination and maintained radio silence for nearly 80 minutes. There was no crash, although air-traffic controllers and safety officials were nearly frantic by the time the plane landed. Had flight data been transmitted continuously, ground-based monitors could have quickly alerted controllers that the autopilot was still engaged and that the plane remained at high altitude when the pilots ought to have been taking command and preparing to land. The controllers could then have radioed the pilots immediately.

Or consider the controversy that followed the loss of EgyptAir Flight 990 in the Atlantic Ocean in October 1999 en route from New York to Cairo. The U.S. National Transportation Safety Board determined that the probable cause of the crash was an error on the part of the copilot, who it said had set the controls to put the plane into a steep dive. The safety board gave no reason why the first officer might have done such a dangerous thing, but it did recommend that a criminal investigation be opened, the implication being that the copilot had committed mass murder and suicide. Of course, the Egyptian government disputed this theory vociferously.

My colleagues and I have proposed a real-time remote monitoring system that would have begun a dialogue with those onboard systems—and would have very likely determined whether the copilot had made errors.

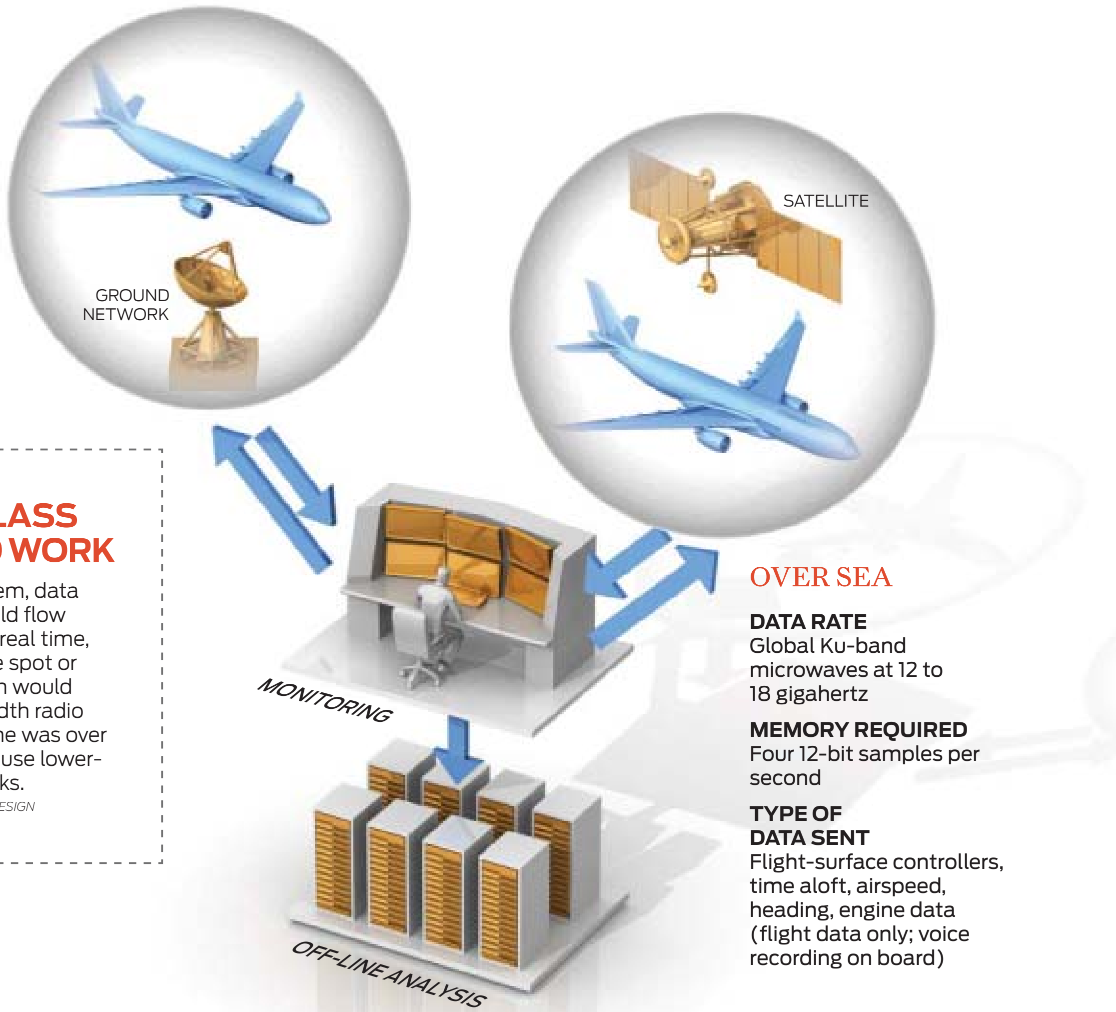
FIRST, SOME BACKGROUND: The original black box was designed by David Warren, of Australia, who as a boy had lost his father in an airplane crash. In 1953, while working as an aeronautical engineering researcher, Warren came up with the idea of an onboard flight-data recorder, following the investigation of a crash of one of the world's first jetliners. The first devices built on his design were installed later in the decade.

The boxes were painted black in those days to fend off the stray rays of light that might have ruined the photographic film that stored the data. Today the boxes store data on memory chips and are painted bright orange, to make them easier to find amid crash debris or on the bottom of the ocean. As always, they are built as sturdily as a wall safe. Since the 1970s, they have been equipped with self-activated ultrasonic beams that broadcast the box's position underwater for up to 30 days.

Today most black boxes—the majority made by L-3 Aviation Recorders, in Sarasota, Fla.—can record 256 distinct streams of digital data, or parameters, per second, and store them all for 25 hours before writing over them. The latest voice recorders can store 180 minutes of conversation, while the older ones store 30 minutes. Both kinds of data are stored in stacked semiconductor dynamic RAM memory boards.

The information recorded, the sampling rate, and the order in which the data are stored differ. The manufacturers supply the software and hardware needed to read and analyze the data and sometimes send representatives to help interpret them. They may have their work cut out for them if the box is dented, twisted under high heat, or has damaged cable interfaces. In

**MEMENTO MORI:** This black box alone was left to tell the story of the crash of EgyptAir Flight 990. *PHOTO: U.S. NAVY/GETTY IMAGES*




## HOW THE GLASS BOX WOULD WORK

In the glass-box system, data from the aircraft would flow to ground stations in real time, to be analyzed on the spot or later on. Transmission would employ high-bandwidth radio except when the plane was over water, when it would use lower-bandwith satellite links.

*ILLUSTRATION: BRYAN CHRISTIE DESIGN*

such cases they must rebuild the interfaces or find other ways to extract data from the wreckage. If the box is damaged, it can take weeks or months to retrieve the information.

Some failures may happen only from time to time, without causing crashes, and so never attract much attention, particularly if the failure does not recur within the 25 hours of data collection. However, if you put together all the data from many flights over many months and comb through them, even these intermittent failures will surely fall into detectable patterns.

OUR PROPOSED ground-based monitoring system would aggregate data in just this way. Investigators could thus examine information from a crashed aircraft for symptomatic patterns, to infer more precisely what had happened to it.

There is nothing new about this methodology. Analysts have used it for years to diagnose computer viruses, malware, and cyberattacks. Manufacturers and the governmental bodies that regulate them also employ it to identify failures in the design or manufacture of automobiles before issuing a recall. It is strange, then, that those responsible for air travel—the first and arguably the most thoroughly researched field in industrial safety—should have put off taking this step for so long.

The data collected by a flight data recorder vary according to whether the aircraft is in the takeoff, landing, or cruising phase. The U.S. Federal Aviation Administration specifies 88 parameters that must be recorded. One typical parameter is variation in altitude relative to a base altitude. Other such parameters are time aloft, airspeed, vertical acceleration, heading with respect to magnetic north, fuel flow, positions of various flight-surface controllers, and engine data. Most parameters are recorded at the rate of four 12-bit samples per second; others, less frequently. An airline may collect additional information for its own use as well.

Back in 2000, my then student Mohamed Aborizka and I figured out the communication requirements for transmitting flight recorder data continuously to a monitoring system on the ground. The airplane would transmit directly to the ground where possible, but when flying high or over water, it would have to resort to transmission via networks of satellites, some high up in geosynchronous orbit, others much lower down. In this way, it would cover even the polar regions. We favor satellites transmitting in the global Ku-band (that is, microwaves at 12 to 18 gigahertz), because they can avoid the interference with physical obstacles that plague terrestrial microwave systems. Also, satellites transmitting in this band can send signals strong enough to allow a receiver to use a very small dish. However, because satellite-borne bandwidth is a limited resource, we proposed economizing on the bandwidth by streaming only flight data, not the cockpit voice recording. The voice recording would go into an onboard recorder,



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as it does today. In fact, to ensure against the loss of communication to the ground station, we suggested that the current black box technology might continue, as a backup.

Most aircraft already shunt some information to ground stations. The data, which come at regular intervals, have to do with the flight path and airspeed, as well as information that maintenance crews need to service the plane when it lands. This system mostly uses VHF frequency-shift keying, which can handle just 16 bits per second, now popular in ships at sea.

The messages now sent to ground stations generally contain 220 bytes at a time in a package called a block, although some messages may span several blocks. We're talking about a paltry transmission rate—less than 2 kilobytes per second per aircraft. However, because several thousand airplanes may be in flight at a time, the combined data may come to perhaps 6 megabytes per second. But today such a volume is hardly prohibitive: A single WiMax connection can download 1 or 2 MB/s, and one of the new 4G phone systems might go as high as 10 MB/s. Solutions to these transmission problems, and the somewhat harder one of mining the vast archive of data, lie within our grasp.

ONE MAJOR PROBLEM does remain: how to get around the lack of a uniform communication medium. The world, after all, is covered by many different wireless systems—some designed for cities, some for rural areas, others for use over the ocean.

To stay in touch with every aircraft, a glass-box system would have to switch among all these communication channels. For example, an aircraft flying over land, at low altitude, can access high bandwidths by tapping into cellphone networks using VHF and UHF, which typically reach no farther than about 200 kilometers. When flying high or over water, satellite communication systems, which have lower carrying capacity, would have to be used instead.

This juggling act is child's play for software-defined radio, which switches among frequencies and communication protocols to achieve high reliability in widely varying conditions and circumstances. Such systems do tend to be expensive, having been designed to operate on a vast number of frequencies. But a glass-box system wouldn't need so many frequencies, which would simplify it considerably.

Today the best satellite-delivered bandwidth operates on the Ku-band and uses the protocols known as MPLS VLAN (multiprotocol label switching virtual local area network). These channels allow specific data to flow to secure Internet Protocol servers on the ground.

It may be necessary to vary the amount of data transmitted according to the status of a flight. For example, more data need to be transmitted during takeoff and landing, when several parameters change rapidly, than during cruising. Similarly, whenever the ground-based monitoring system notices something unusual, it requests additional data to clear things up. To handle this fast-shifting demand for data, a glass-box system must incorporate dynamic scheduling, doling out more or less channel bandwidth to different aircraft.

A GLASS BOX must make the most of limited bandwidth. Just as graphics-display programs leave untouched those pixels that depict a clear blue sky while reserving most of their processing for the pixels that depict drifting clouds or darting birds, a glass box might transmit only the parameters that show significant deviation from a previous sampling. Another trick is to hold back some data whenever bandwidth is tight and then transmit data when bandwidth becomes available again.

It would be unwise to delay transmission by first running flight data through an onboard recorder before transmitting it to the ground. One way around the problem is to add a port to the onboard recorder, so that logging of data could proceed on board and on a ground-based server simultaneously.

Once the data are logged on the ground, expert systems could sift through vast troves of historical information to spot abnormal and possibly catastrophic behaviors. Designing these systems is the main challenge, for it goes beyond just juggling data—such a system must emulate human judgment. Yet this wouldn't be too hard to accomplish. After all, the expert system need not be omniscient; it would be enough if it merely caught the attention of air-traffic controllers, alerting them to possible trouble.

Because the volume of data that must be saved amounts to hundreds of gigabytes per day, it may be necessary to save only select samples of it. Armed with such compressed data, expert systems and human experts working in tandem could identify recurring errors due to design problems, maintenance problems, pilot training, weather conditions, and airport or runway conditions. The knowledge gained could also be used for training pilots, air-traffic controllers, and accident investigators.

It has been a decade since I first proposed the glass box, and progress toward it has been shamefully slow. The main hurdle is sheer institutional inertia. The strongest institutional opposition has come from airline pilots, who fear that the practice would lead to full-scale monitoring of their work, much as it has for interstate truckers. In 2000, in reaction to the EgyptAir crash, the FAA tried to mandate cockpit cameras, but the U.S. pilots' union managed to prevent it. The rest of the world, which followed the U.S. lead, has also done nothing.

Concern over privacy and professional autonomy need not be a sticking point. To assure the privacy of pilots, airline companies, and aircraft manufacturers, all you need to do is secure the communications between onboard and ground-based systems and to protect the saved data from prying eyes. Data encryption techniques seem more than adequate for this purpose; using a new encryption key each time an aircraft takes off could further enhance the protection. Remember, the point of the glass box is not to feed lawsuits but to enable professionals to learn from experience.

To keep sensitive information out of the hands of insurers, airline executives, and lawyers, it should be enough to emulate privacy policies already in place in the United States in other fields—for instance, the Health Insurance Portability and Accountability Act for patients' medical records. The glass-box system could achieve this goal by giving the firm that operates the ground-based systems exclusive rights to the data it stores.

I'm heartened to hear that Airbus, in France, is exploring these ideas, but one company cannot hope to change institutionalized practices in the world at large. The U.S. government's Next Generation Air Transportation System, under the control of the Joint Planning and Development Office, ought to take up the challenge.

The black box was good, in its time; the glass box is its logical successor. ❑



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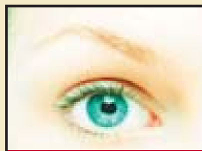

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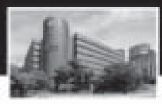

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Successful applicants must have a doctoral degree in electrical engineering or a related discipline, and a commitment to excellence in research and teaching. Applicants need to complete employee application registration at **http://www.yonsei.ac.kr/eng/news/employment/2011faculty.asp** and also need to submit the following PDF files to **ee-chair@yonsei.ac.kr**: cover letter, statement of research objectives, probable instructing lectures, curriculum vitae, diplomas, doctoral thesis, publication list, all papers published since March 2007, and all accepted papers. Also, two letters of recommendation should be sent separately to the address below. **For full consideration of appointment beginning in 2011, applicants should submit all application materials by August 23, 2010.**

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Ministry of Higher Education
## King Fahd University of Petroleum & Minerals
Dhahran, Saudi Arabia

### College of Engineering Sciences
**ELECTRICAL ENGINEERING DEPARTMENT**

The **Electrical Engineering Department** at King Fahd University of Petroleum & Minerals (KFUPM) in Dhahran, Saudi Arabia, invites applications for faculty positions at the rank of Associate Professor or Full Professor starting from September, 2010 in the following area :

### POWER SYSTEMS WITH HIGH VOLTAGE and PROTECTION

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Two-year renewable contract. Competitive salaries based on qualifications and experience. Free furnished air-conditioned on-campus housing unit with free essential utilities and maintenance. The appointment includes the following benefits according to the University's policy: air ticket/s to Dammam on appointment; annual repatriation air ticket/s for up to four persons; assistance with local tuition fees for school-age dependent children; local transportation allowance; two months' paid summer leave; end-of-service gratuity. The KFUPM campus has a range of facilities including a medical and dental clinic, an extensive library, computing, research and teaching laboratory facilities and a recreation center.

**To apply :**

Candidates should send their CV/Resume, copies of their degree, diplomas, transcripts, and the application forms (can be obtained from the site: **http://www.kfupm.edu.sa/fpa/**) to the following address :

**Dean of Faculty & Personnel Affairs**
DEPT. REF.No. EE-101
KFUPM Box 5005, Dhahran 31261, Saudi Arabia
E-mail: **faculty@kfupm.edu.sa**
Fax: **+966-3-860-2429** or **860-2442**

Please always refer to the above DEPT. REF. No. in all correspondence

For more information, please visit the following website/links:
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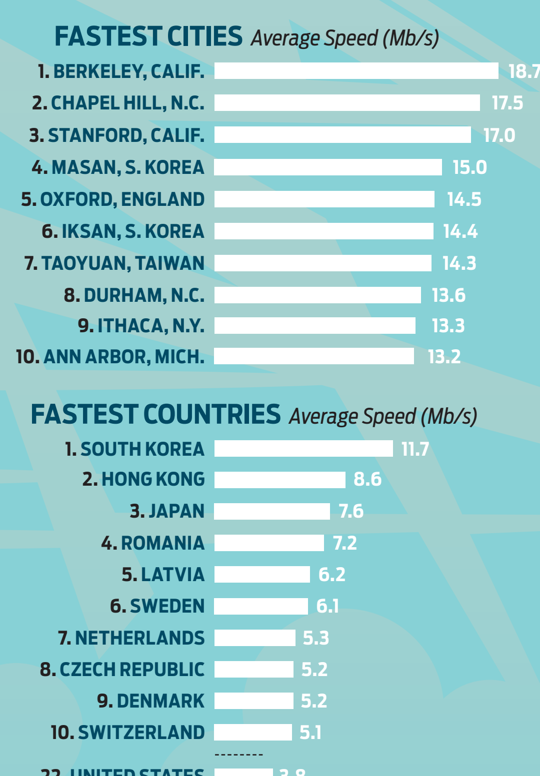
# Who Has the Fastest Internet?

CALL IT the real estate agent's rule: The speed of your connection to the Internet depends on location, location, and...the device you're using.

Akamai Technologies, the giant Internet service provider, produces regular state-of-the-Internet reports. Every time you connect to an Akamai server (for instance, to download a video), it records the IP address, the size of the file delivered, and the time it took to deliver it. The company aggregates these numbers geographically to obtain a rough picture of how Internet traffic is moving around the world.

If you like fast connections, you'll love South Korea, which has an average speed of 11.7 megabytes per second. That gives it a huge lead over No. 2, Hong Kong (8.6 Mb/s), to say nothing of No. 22, United States (3.8 Mb/s). If you can't move to a new country, you can still move to a university town. The top three cities in the world are Berkeley, Calif. (at 18.7 Mb/s, much faster than South Korea), Chapel Hill, N.C., and Stanford, Calif. Oxford, England (No. 5), also fits into this mold.

Paradoxically, as Internet connectivity becomes ubiquitous, it gets worse—the average connection in South Korea, as well as in some of the leading U.S. states, has gotten slower over the past year. Korean downloads were 29 percent slower in 2009 than 2008, and they were 24 percent slower in the fourth quarter than in the third quarter. Blame it on smartphones. Looking at speeds before and after the November 2009 release of the iPhone there, David Belson, Akamai's director of market intelligence, wrote in the most recent report, "We believe that this launch was likely responsible for the significant drop in South Korea's average observed connection speed in the fourth quarter." *—Dana Mackenzie*

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