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THE MAGAZINE OF TECHNOLOGY INSIDERS
01.08

SPECIAL REPORT

WINNERS & LOSERS 2008

THE BEST & WORST TECHNOLOGY PROJECTS

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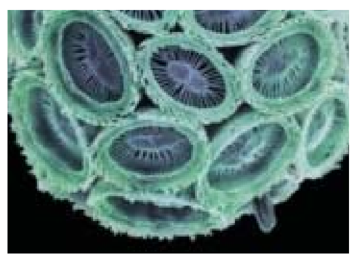

HOT OR NOT?
IBM'S Dan Edelstein pokes holes in chips; coal goes green in a German power project; oceans of phytoplankton nibble on carbon.

THIS PAGE: CLOCKWISE FROM TOP LEFT: CHRIS MUELLER; PLAMEN PETKOV; STEVE GSCHMEISSNER/ SCIENCE PHOTO LIBRARY COVER: FREDRIK BRODEN

SPECIAL REPORT: WINNERS & LOSERS 2008

FRONT

UPDATE

OPINION

DEPARTMENTS

ieee spectrum

volume 45 number 1 international

01.08

SCANNING THE SURFACE: Is the Microsoft Surface the next big thing in touch-screen displays, or is it doomed to fail? You tell us online.

PHOTOS: LEFT: MICROSOFT; RIGHT: VIVEK VARSHNEY

AT SPECTRUM ONLINE

WWW.SPECTRUM.IEEE.ORG

YOU TELL US

A TOUCH-SCREEN computer that works like an iPhone but is the size of a coffee table. A whisper-quiet, ecofriendly motorcycle. A pen that tracks what it has written while recording what it hears. A flying car that takes off like a plane and lands like a helicopter. Eyeglasses that give you an HDTV video experience. A 4-gigabit-per-second wireless A/V connection. All these technologies—according to their inventors—are ready for prime time. But are they? We explain the concepts, and you decide whether these six products are destined to be winners or losers.

ONLINE FEATURES:

SPECTRUM EDITORS TAKE YOU inside the Consumer Electronics Show with video reports from Las Vegas.

LEARN HOW AN ITALIAN town's buried RFID transponders keep blind people on the right track.

DELVE INTO THE INNER workings of the world's tiniest refrigerator, the thermal transistor.

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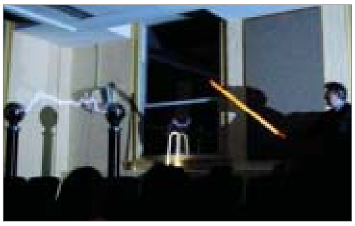
AVAILABLE 7 JANUARY ON THE INSTITUTE ONLINE

INNOVATION INSTITUTE GEARS UP

A lot has happened at the IEEE-USA Innovation Institute since it launched in 2007. Most recently it held its first forum, which explored various aspects of innovation, including product development and navigating corporate culture.



STUDENTS SPARK INTEREST IN IEEE WITH PARTY

The IEEE student branch at Worcester Polytechnic Institute, in Massachusetts, really knows how to make sparks fly. In November, the branch held its second annual Spark Party, complete with a demonstration of a pair of gigantic tesla coils and other loud, electrifying crowd pleasers.

WORKSHOP COVERS ELECTRICAL SAFETY

Find out the latest in electrical safety at the IEEE Industry Application Society Electrical Safety Workshop, set to take place 18 to 21 March, in Dallas. The conference will cover improvements in electrical standards and regulations, how to prevent electrical accidents and injuries in the workplace, and more.

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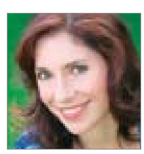
contributors

ROBERT W. LUCKY

Don't be alarmed that Robert W. Lucky's Reflections isn't on the back page of your magazine. This IEEE Fellow, now retired from Telcordia Technology, continues to write his long-standing column. You'll find Reflections further up, on p. 17.

JEFF NEWTON

For this month's Careers [p. 18], Jeff Newton worked inside a jet simulator, which he says is one of the coolest locations he's shot in: "It was like being in an episode of '24.'" His photos have been published in *Condé Nast Portfolio*, *Forbes*, and *SLAM*. Look for Newton in your local coffeehouse, especially if you're in Phoenix or Los Angeles: he's the crazy-haired guy on the laptop chain-drinking shots of espresso.



SUSAN KARLIN

In Careers, Susan Karlin reports on EE Robert "Bobaloo" Rickard's decision to become a U.S. Air Force fighter pilot [p. 18]. Nicknames like his were usually given to commemorate "something funny you did, or something you screwed up," Rickard says. Karlin tried to get an honorary pilot nickname herself but was told she had not done anything unprintable enough to merit one. She says she'll keep trying.

KENNETH R. FOSTER

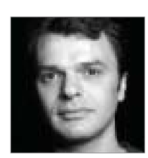
An IEEE Fellow and a professor of bioengineering at the University of Pennsylvania, Kenneth R. Foster has been a frequent reviewer of books and software for *IEEE Spectrum*. In this issue, he considers the latest work of Charles Perrow [p. 20], best known for his study of industrial accidents. Most recently for *Spectrum*, Foster cowrote "RFID Inside: The Murky Ethics of Implanted Chips" [March 2007].

FRANCISCO GUERRERO

Geophysicist Francisco Ortigosa was photographed by Francisco Guerrero for "Solving the Oil Equation" [p. 24], one of our winners. Shooting the MareNostrum supercomputer in Barcelona, Guerrero says, was "like discovering a hidden world. At the head of the path sat the old chapel structure, and within its ancient walls and stained-glass windows rests this fantastic piece of 21st-century technology. Imagine your desktop computer housed inside an 18th-century antique box."

DAVID KUSHNER

Contributing Editor David Kushner wrote this month's winner "Make Your Own World With OLIVE" [p. 37] about a new software package that lets companies create their own virtual worlds. Kushner's previous article for *Spectrum* was "Playing Dirty," in our December issue. He blogs for us at http://blogs.spectrum.ieee.org/gizmos.



PLAMEN PETKOV

Bulgarian-born Plamen Petkov was excited to get his hands dirty shooting for this month's winner "Restoring Coal's Sheen" [p. 49]. Given several samples of bituminous and anthracite coal, he chose one that surprised and fascinated him with the "mesmerizing shine and tonalities of black."

CLOCKWISE FROM TOP LEFT: JEFF NEWTON; DAVID GARCIA GONZALEZ; BETH KELLY; PLAMEN PETKOV; KENNETH R. FOSTER; CARIN BAER

back story

As I Clearly Stated...Loser

When accused of inconsistency, the British economist John Maynard Keynes is supposed to have responded, "When the facts change, I change my mind. What do you do, sir?"

It's a fallback position for every politician, publicist, and pundit, says Senior Editor Philip E. Ross [above], who now invokes it to explain his own change of position on Nantero. He's called the Woburn, Mass., company a winner three times over five years, for three magazines, including this one. This month, though, he places it in the unfortunate second half of *IEEE Spectrum*'s "Winners and Losers" list.

In 2002, writing in *Red Herring* magazine, Ross extolled Nantero's idea of using carbon nanotubes to store data permanently, as flash memory does, while packing in far more data and accessing it far faster. He quoted the company as saying it would have a commercial prototype within "one to two years." Sure, Ross also quoted skeptics, but only in the "to be sure" paragraph that generally follows a long passage arguing in the opposing direction.

Two years later, in another science magazine, Ross lauded Nantero for finally setting up a production line for its nanotube chip. He also wrote up the company at greater length for *Spectrum* [see "10 Tech Companies for the Next 10 Years," November 2004], saying that "these little tubes could turn out to be very big indeed."

He notes that Nantero's technology still seems as ingenious as it ever did. Rather than specify the structure and placement of particular tubes—a problem nobody has come close to solving—the company's device averages the electronic properties of many tubes.

So, what change does Ross cite to justify his change of mind? "The passage of time," he responds. "It has been six years since Nantero started saying its chip would be out in just another year or two, and I just don't believe it anymore." ❏

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. 45, no. 1 (INT), January 2008, p. 7, or in *IEEE Spectrum*, Vol. 45, no. 1 (NA), January 2008, p. 13.

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RANDI SILBERMAN

Technology will continue to redefine publishing and the way we develop and share our most creative and powerful ideas

spectral lines

Technology Innovation Is *Spectrum*'s Message, Whatever the Medium

OVER THE past 20 years, technology has tsunamied publishing. E-mail, the Internet, and desktop publishing, to name a few, have engulfed the industry. Virtually all print magazines have had to redesign and realign themselves to withstand these tidal forces.

We're no different. Our print redesign, introduced in this issue, forced us to think about all the ways we are—and will be—delivering *IEEE Spectrum*'s stories to you.

What's changed in print? On the graphics side, we've moved to an elegant design executed for us by Research Studios. The number of pages every month will remain about the same—but we hope to make better use of them. As you can tell, we like it. If you don't, let us know.

On the content side, a new section in the front of the book called Update is full of shorter and punchier articles. More and more of these kinds of stories will be making their way to Spectrum Online (http://spectrum.ieee.org), where we can take advantage of the Web's 24/7 timeliness and multimedia features like audio and video. Robert W. Lucky and Paul McFedries will move up to the front with Update, and the last page of the magazine will now be devoted to The Data, a monthly story that lends itself to statistical treatment. This month's numbers reveal how statistics can be used to fuel different points of view on greenhouse-gas trends.

Spectrum Online will continue to be home to our blogs, podcasts, and videos. Over the coming year we are planning to add even more features for the practicing technologist—more Webinars, white papers, and the like—to help you keep up with developments and significant new tools.

There are lots of reports in the publishing world about the ongoing demise of print, and we think they're greatly exaggerated. But we also know that Spectrum Online, the digital edition of *Spectrum*, our e-mail alerts, RSS feeds, and other editorial delivery platforms are critical to getting information to you whenever you want it, wherever you want it in this information-hungry age.

It's clear that technology will continue to redefine publishing and the way we develop and share our ideas. Literate editors at today's magazines must understand and work in many forms of media. Reading and writing are no longer enough. So as our digital content moves from media to media, from format to format, from device to device, we will move along with it.

What hasn't changed? Our passionate commitment to bringing you the best and most important stories about success and failure in technological innovation is unwavering—as you will see when you turn to our Winners & Losers feature in this issue. We'll keep you informed and amazed by developments springing up all around you. Occasionally, we might even surprise you with something you didn't know about your own field.

You might be a print-loving digital immigrant who remembers a time when there was no Internet, and maybe no personal computer, and certainly no BlackBerry buzzing in your pocket. Or maybe you're a digital native who can't imagine life without a cellphone and T1 access who reads everything online. Either way, *Spectrum* will continue to bring you the ideas and inventions that are shaping our world. —SUSAN HASSLER

We would like to express our thanks and gratitude to all who made the print redesign possible: John Schmitz of Research Studios; *Spectrum*'s Mark Montgomery and his art team: Laura Azran, Brandon Palacio, and Randi Silberman; and Bryan Christie Design, which does our information graphics. We'd also like to thank the IEEE's production group, notably Peter Tuohy, Roy Carubia, Bonnie Nani, and Felicia Spagnoli. Finally, we would like to thank the members of the IEEE for their ongoing support.

forum

DON'T CALL IT WARFARE

ROBERT N. CHARETTE's article, "Open-Source Warfare" [November] is interesting, but its use of the word *war* to describe the current situations in Iraq and Afghanistan is erroneous. Both wars ended years ago—in Afghanistan, when we defeated the Taliban-led government, and in Iraq, when we ended the rule of Saddam Hussein and disbanded his army. In both countries, the U.S. military forces and their allies are now an occupational force supporting an unstable government. There are people in both countries who want us to leave, and they fight like the Chechnyans fight the Russians and the Palestinians fight the Israelis. Of course, these small groups are no match for the armies they are pitted against, and they use the most effective weapons and technologies they can get their hands on. In Iraq today, cellphones and the Internet are the technologies of choice.

Decades ago, guerillas also used the weapons available to them. They used hit-and-run tactics because they could not defeat an organized army. So when Charette writes "when the wars in Iraq and Afghanistan finally end," he really means "when we eventually decide to leave." Rather than ponder how the U.S. Department of Defense procurement system should be changed to equip an occupying army, the real questions to be answered are these: should an army be used as an occupying force? Are the technologies developed for armies suitable for occupation in a hostile environment?

ERIC HOLZMAN
IEEE Senior Member
Ellicott City, Md.

KUDOS TO Robert N. Charette and to the editors of *IEEE Spectrum* for publishing this article. As a 40-year veteran of the defense industry, now retired, I found the article refreshing, informative, clear, crisp, and concise. It is the best article I have read in *Spectrum* this year.

ELI DALABAKIS
IEEE Life Senior Member
St. Petersburg, Fla.

PATENT PROTECTION

IN REFERENCE to "Keeping Score in the IP Game" [November]: Lately I keep seeing articles whining about two things—U.S. patent protection is too strong, and U.S. R&D is too weak. You can't have it both ways. If you weaken patent protection, then you also take away much of the value of industry-sponsored research, thereby weakening R&D. It makes no sense for IEEE members to promote weaker patent protection, because patents are good for engineers. Strong patent protection may be a significant chunk of management's costs, now that they outsource so many jobs. But it is good for engineers.

KEN KERPEZ
IEEE Fellow
Piscataway, N.J.

POWERWORKS DOESN'T

CAN THERE be any more absurd idea than the Coleman Powerworks power inverter for cars [Resources, November]? There's something very wrong with this picture: the engine's alternator generates alternating current (ac), which is converted to direct current (dc) to recharge the battery and is also distributed to a cigarette-lighter receptacle, into which we're supposed to insert a cigar-shaped plug to send that dc power to an inverter to change it back into ac so that we can plug in our laptop's power converter, which changes it back to dc to power the laptop! To recap: ac to dc to ac to dc. That doesn't seem like sound engineering. It's more like Edison and Tesla are still fighting it out in the backseat of my car.

Why not put in place a professionally engineered electrical system? What's needed is a simple auto dc distribution network, with small, standard, purpose-built dc plugs, into which we can directly plug music players, GPS units, cellphones, DVD players, and the like. That sounds like a job for the IEEE.

RICHARD CAMPBELL
IEEE Member
New York City

CORRECTION

In "Charge of the Ultracapacitors" [November], the sentence "The sheet is placed in a vacuum, heated to 650 °C, and exposed to a thin hydrocarbon gas, perhaps ethanol or acetylene" should have referred to ethylene, not ethanol.

BUT DOES IT RUN ON ETHANOL?

THE BIG Picture [News, November] featured a photograph of the Pivo 2 concept car. This is a classic example of bad product naming. "Pivo" means "beer" in Czech and other Slavic languages.

RUSSELL SHANNON *IEEE Member, Mount Holly, N.J.*

LETTERS do not represent opinions of the IEEE. Short, concise letters are preferred. They may be edited for space and clarity. Additional letters are available online in "And More Forum" at http://www.spectrum.ieee.org. Write to Forum, *IEEE Spectrum*, 3 Park Ave., 17th floor, New York, N.Y. 10016-5997, U.S.A.; fax, +1 212 419 7570; e-mail, n.hantman@ieee.org.

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update

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CONNECT THE DOTS: To identify this image of the Great Nebula in the constellation Orion, software locates stars [red circles] and connects them in sets of four [green shape]. An algorithm then predicts where other stars should be [green circles] for each matching set in a database and looks for alignment.

PHOTO: JERRY LODRIGUSS/ ASTROPIX

Searching the Sky

Image-recognition software for astronomy pictures brings professional and amateur astronomers together

EVERY NIGHT, thousands of amateur astronomers in their backyards point digital cameras and telescopes at the same bits of starry sky that professional scientists scan from mountaintop domes. Although both groups collect thousands of images, they rarely use one another's results. While amateurs are more interested in aesthetics, professionals need hard numbers.

In a first step toward bridging this divide, a team of astronomers and computer scientists has created pattern-recognition software that may provide an easy way for the two groups to collaborate by making their astronomical images equally searchable. The Web-based application, scheduled for a beta release in early 2008 at Astrometry.net, can analyze nearly any field of stars and, based on the particular geometric relationships of the stars, determine exactly which part of the sky the photo captures. The terrestrial equivalent would be a program that could pinpoint the latitude and longitude of your house from an aerial photograph of your street.

"The vast majority of astronomical data is in disarray," explains David Hogg, a New York University astronomer in New York City who three years ago conceived of the project with his high school classmate Sam Roweis, now a computer science professor at the University of Toronto. Hogg points to boxes of magnetic tape on his office shelf containing digitized images and explains that it would be easier to apply for new telescope time and re-collect the data than to get what he needs from the tapes. As another example, he notes that Harvard University has one of the world's largest archives of astronomical images—nearly half a million plates dating from the era before digital imaging—but the handwritten logs make

"The vast majority of astronomical data is in disarray" —David Hogg, New York University astronomer and cocreator of Astrometry.net

update

them hard to search, so many just gather dust.

Automatically determining an image's location in the sky provides the first step toward making both forgotten professional data and images from amateurs searchable and standardized. "Professional astronomers are great with taking pictures of the sky," says Roweis, but comprehensive surveys happen only once or twice a decade. "Amateur astronomers, on the other hand, take pictures every day," which can be valuable for studying fast-changing astronomical events, he says.

Astrometry.net's search software begins its analysis by looking for the brightest stars in the image and then uses sets of four such stars to draw four-sided shapes that Hogg and his colleagues call quads. Each quad is like a fingerprint for a particular part of the sky. But because there are so many stars in the sky—a few thousand visible to the naked eye alone, and billions visible to telescopes—many of these fingerprints look similar.

Rather than trying to find a perfect match, the program looks at many possible matches in a database of more than a billion stars, according to Dustin Lang, a University of Toronto Ph.D. student who, together with fellow student Keir Mierle, wrote most of the code. For each matching quad, the computer compares surrounding stars in the image to those predicted by information in the database and reports a successful match only when the stars' positions correspond with little discrepancy.

To attract more amateur interest, Hogg and his team hope to combine their program with online virtual planetariums such as Google Earth's Sky feature, Microsoft's upcoming World-Wide Telescope, and an open-source project called Stellarium.

Once launched, Astrometry.net will allow amateurs to superimpose matching images from the Hubble Space Telescope and other professional sources on top of their own photos, says Hogg, or to identify all the stars and constellations in a backyard snapshot. A small group of testers has already found new ways to use the open-source software, and Hogg and Roweis plan to make it available to the public as soon as they secure funding to support more users. —Joshua J. Romero

NTT DEVELOPS A SMELL-O-PHONE

Not content to serve only its customers' eyes and ears, Japan's NTT Communications, of Tokyo, has just finished testing an Internet-connected odor-delivery system to be used by retailers and restaurants to attract customers. In the test, a device [right] emitted cocktails of fragrances mixed in the machine according to recipes delivered over the Internet. The scents were intended to pull passersby into a pub in an underground mall in Tokyo. What drives Japanese mall-goers to drink? NTT's researchers are betting that for men, at least, it's a peculiar lime aroma—used in combination with a flat-panel display showing frolicking bikini-clad women.

more at http://spectrum.ieee.org/jan08/smelltoo

NTT

BRYAN CHRISTIE DESIGN

Chip Design Hardwires Security

New microprocessor architecture keeps hackers at bay without compromising security

COMPUTER SECURITY is war. Security experts are in a constant arms race against the ingenuity of hackers. What's more, the security specialists are often working with one hand tied behind their backs because, unlike their adversaries, they are constrained by privacy concerns. But researchers at Princeton University have developed a new chip architecture that could one-up the hackers while easing the tension between the opposing poles of security and privacy.

Princeton electrical engineering professor Ruby B. Lee and her co-workers invented what she calls the Secret Protection computer architecture. Computers built using the new technology can receive sensitive information for a short time (designated by a trusted authority), after which the information is cleared out of the device that accessed it. Lee expects the first adopters of this architecture to be makers of devices for first responders, such as firefighters and EMTs. But, she says, it can be adapted to any mainstream microprocessor to prevent infection by worms and viruses and to theft-proof movies and other downloaded media.

In the first-responder scenario, an EMT may encounter a person who has been in a car accident and who may be allergic to a medication but is unconscious and unable to communicate. With Lee's architecture, a device given to the EMT by a hospital, for instance, could obtain a patient's entire medical record, but the EMT could access only the information relevant to this emergency. And after a preset period of time, that information would vanish from every memory location in the machine. "The hospital can deliver these partial medical records so the guy in the field doesn't know everything about you," says Roger Golliver, a senior principal engineer at Intel and cryptography expert.

The vanishing act is possible because in Lee's design, the security is built in as a primary hardware mechanism, not as a software afterthought. The Secret Protection architecture relies on two elements embedded in the device hardware: the storage root key and the storage root hash.

The storage root key functions like a master key that enables access to secure files. "It's something that opens a safe that contains another key for each file," Golliver says. The storage root hash, by contrast, is like an alarm system, ensuring that the contents of the safe haven't been tampered with. If the hash is compromised, the data is erased or marked as suspicious.

Lee's system runs constant checks to make sure these hashes haven't been hacked. Because the root key, the root hash, and the software they protect are linked in Lee's architecture, "you can wipe out the roots, but if you do that, you also wipe out all the trusted software they protect," says Lee.

Lee adds that her architecture can go into any mainstream microprocessor, but Golliver has some doubts. "In her model, a trusted authority provides the device," he says. "That's harder to do in the PC world." Privacy advocates, he recalls, went ballistic in 1999 when Intel put a hardware-based processor serial number into each of its Pentium III chips. The resulting uproar forced Intel to abandon the practice.

Lee counters that with her system, no key is burned into the device by the manufacturer; rather, a PC owner could act as his own "trusted authority," initializing the device himself in order to protect his information. —SARAH ADEE

news briefs

THE OTHER DIGITAL DIVIDE

According to recent Organisation for Economic Co-Operation and Development statistics, the United States ranked a meager 14th in "average advertised broadband download speed" at 8.86 megabits per second. That's less than a tenth the speed in world leader Japan and about one-fifth that in France and South Korea. A common excuse for the poor ranking is that the U.S. population is more spread out and therefore more difficult to serve. But U.S. broadband speeds even fall short of sparsely populated Australia. See how the top 20 countries line up at http://spectrum.ieee.org/jan08/bbrates.

PHOTO: SERGEI SVERDELOV/ISTOCKPHOTO

"This is the entire knowledge of this period" —Markus Brantl, director of the Bavarian State Library's digitization center

update

Book-Scanning Robots Digitize Delicate Texts

21st-century robots read 16th-century Bavarian books

Students come from the world over to study the Bavarian State Library's collection of works from the time of Martin Luther. But this year, the Munich institution's 450th in existence, the most voracious readers of its ancient collection will be a pair of robots. In the library's basement, two machines called ScanRobots are whirring away at 700 pages per hour and are scheduled to digitize all of the four-century-old books in the library, some 7.5 million pages' worth, by 2009; the scanned books will be put online.

Markus Brantl, director of the library's digitization center, says it's vital to digitize unique content like the 16th-century collection, both for preservation purposes and to open access for readers, academics, and laypersons alike. "This is the entire knowledge of this period, [from] theology to mathematics—everything," he says. But in making the material much more widely available, the Bavarian library is also giving a boost to a scrappy band of robot engineers from Austria's Vienna University of Technology, who are out to upset the scanning market.

The ScanRobots are the debut project for Treventus Mechatronics, which spun out of the university after Professor Wolfgang Zagler sketched out the idea for the machines on a train ride in 2002. What makes the robots unique is their ability to scan books that are opened only to a 60-degree angle, which keeps the spines and pages of older books from being damaged by the strain of being fully opened. The US $125 000 machines work by holding the pages in place with soft suction and moving a scanning head vertically while the book is held open underneath. The scan head contains two 30-degree glass prisms that project onto high-quality cameras. The head doesn't touch the page—the scanning camera records both open pages through the prisms simultaneously in high resolution as it methodically moves up and down, like an oversize sewing machine needle. Gentle air jets turn each page after the scan is complete. Nightmares of sucking pages out of the Gutenberg Bible will remain just that, idle anxiety dreams, promises Stephan Tratter, a former grad student at the university and now head of marketing and R&D at Treventus.

A DELICATE TASK: A pair of extra-gentle digitizing robots scan books at the Bavarian State Library. *PHOTOS: TREVENTUS MECHATRONICS*

Tratter says the firm got off the ground only after winning a few European research contests for seed money. Its first robot prototype went through trials at the University of Innsbruck, in Austria, last spring, and the firm now has robots at three other sites.

Even though the ScanRobot doesn't have legs or wheels, Tratter says it is indeed a robot and not just a glorified photocopy machine. "This one turns the pages automatically. In principle, it has no need of an operator," he says, although with such delicate projects as the one in Munich, there will be one. "The robot is also able to recognize errors and learn not to make them again."

Brantl is glad to hear that. His digitization department has been working for 10 years and now has 23 000 books online. The ScanRobots will surpass that figure this year alone. The library ordered the Austrian book-bots last fall to handle delicate digitization work like the 16th-century project. The Bavarian State Library, one of the largest in the German-speaking world, has already cast its lot with Google in the sometimes controversial struggles over digitizing and posting online the vast volume of literature that no longer is covered by copyright law. When the job is done, says Brantl, the Bavarian library will have digital versions of 1 million of its 9 million possessions, including its 80 000 medieval manuscripts and 20 000 incunabula (printed books made before 1501).

—Michael Dumiak

Engineers Graduate From New Afghan Military Academy

"East Point" technologists to rebuild Afghanistan's infrastructure

IN 1802, the United States established a military academy at West Point, N.Y. Its mission was to ensure that the fledgling nation would have an educated officer corps and a steady source of skilled engineers to design, build, maintain, and defend the nation's infrastructure. Two centuries later, Afghanistan is trying the same formula with its new military academy in Kabul. The academy will graduate its first class of engineers this month.

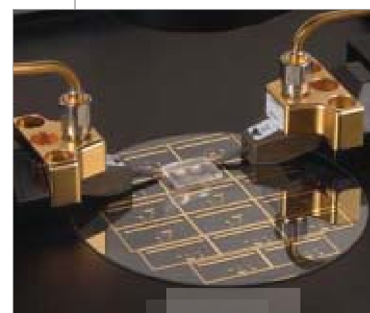
The government hopes graduates will help rebuild roads, bridges, and an electricity grid ravaged by decades of war and neglect. Just as important is "creating a professional army officer corps that supports Afghanistan's newly drafted constitution and is not fractured by separate allegiances to local warlords," says U.S. Army colonel and IEEE senior member Barry Shoop, one of dozens of West Point faculty members who helped plan and build the school and continue to advise its Afghan faculty and staff.

Modeled on West Point, the National Military Academy of Afghanistan is often referred to as "East Point." The 109 young men who were sworn in as cadets in 2005 underwent what Shoop calls a rigorous Western-style university curriculum. All will graduate with bachelor of science degrees in one of seven majors, which include civil, mechanical, systems, and information systems engineering. The four-year course of study combines engineering instruction with the study of calculus, statistics, chemistry, and physics. Students also take courses in regional, world, and military history as well as three years of foreign language instruction. Graduates of the academy are all expected to speak, read, and write in both Dari and Pashto, two of the primary dialects spoken by most Afghanis, as well as English or Turkish.

The graduates, who will be commissioned as second lieutenants in Afghanistan's national army, are obligated to serve 10 years on active duty in exchange for the tuition-free undergraduate education and free books, supplies, housing, and food they receive while attending the academy. This service commitment has not hampered enrollment, says Shoop, who is the chairman of West Point's electrical engineering department. Applications increased by 50 percent to 1789 in 2007.

When asked what East Point will do for Afghanistan, Shoop mentioned the refurbishment of the campus, which is on the site of a former Soviet air academy. "When we identified the site," he says, "we found buildings that were structurally sound but had no power and no running water, on grounds littered with land mines." But with the expertise of engineers from West Point and an assist from some U.S. Navy engineers, Afghan army personnel restored the basic infrastructure, setting the stage for the addition of features that are critical to running a modern university, such as a computer lab with Internet access. "The changes there are emblematic of what can occur across the country when the academy's graduates go back to their home regions and share the benefit of their education," Shoop says. —WILLIE D. JONES

ON THE MARCH: Some of the first engineers who will graduate from the National Military Academy of Afghanistan. PHOTO: SGT. JOE MCFARREN/U.S. ARMY



news briefs

MICROSCOPIC MICROWAVE OVEN

Engineers at the U.S. National Institute of Standards and Technology and George Mason University, in Fairfax, Va., say they've made what's probably the world's smallest microwave oven. The device can heat a pinhead-size drop of liquid within an oven chamber that's about half as wide as a single hair and a little shorter than an ant. They built the oven as part of a lab-on-a-chip for performing DNA forensics and other complex biochemical analyses on very small samples of material.

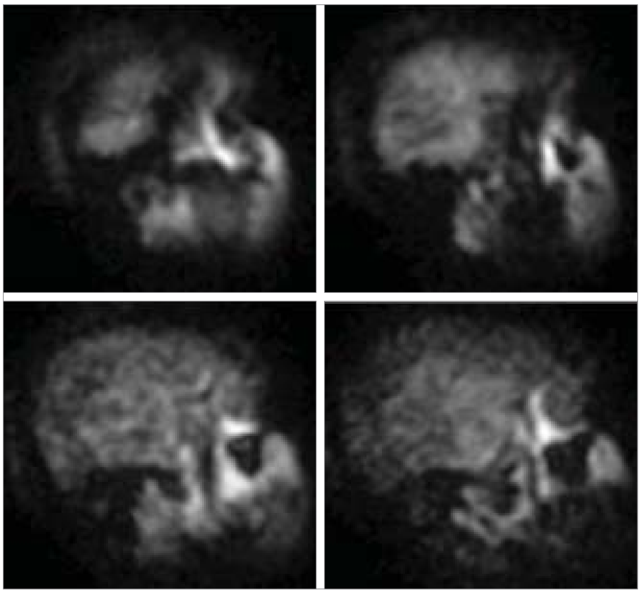
PHOTO: NATIONAL INSTITUTE OF STANDARDS AND TECHNOLOGY

A weak magnetic field MRI machine might cost as little as US $100 000 compared with $1 million or more for a standard MRI system.

update

A Weaker, Cheaper MRI

Magnetic fields that would barely budge a compass might find tumors faster



HEAD SHOTS: Four slices of researcher Vadim Zotev's head are the first medical images made with low-magnetic-field MRI.
PHOTO: VADIM ZOTEV/LOS ALAMOS NATIONAL LABORATORY

RESEARCHERS AT Los Alamos National Laboratory have made what they say are the first images of a human brain using magnetic fields a hundred-thousandth the strength of conventional magnetic resonance imaging (MRI), paving the way for lower cost medical images that might be better at detecting tumors.

Though the resolution is much lower than that in conventional MRIs, the images "show we have a potential for pretty good results," says Vadim Zotev, a researcher in Los Alamos's applied modern physics group. (That's his head in the images.)

MRI works by subjecting the human body to a strong magnetic field, which causes the proton in the nucleus of each hydrogen atom in the body to line up along the magnetic field's lines of force. An RF pulse briefly knocks the protons out of alignment. As they snap back into position, the protons emit an RF signal that can be used to construct a three-dimensional image. Most MRI machines have a magnetic field of about 1.5 teslas, strong enough to yank metal objects out of the hands of the unwary.

Zotev's machine, however, generates a magnetic field of only 46 microteslas, roughly the same strength as the Earth's magnetic field. Few protons align at this lower strength, so he must first apply a 1-second prepolarization pulse—at 30 milliteslas, it's about as strong as a small bar magnet—which primes the protons to respond to the microtesla field. To detect the weaker signals, he uses an array of seven supersensitive magnetometers called superconducting quantum interference devices, or SQUIDs. In a SQUID, electrons are in an odd quantum state that allows individual electrons to move in two directions at once and interfere with themselves. The amount of interference depends on the strength of an external magnetic field and translates into a measurable resistance to the flow of current in the SQUID.

Because it needs fewer costly magnets, a weak-magnetic-field MRI machine might cost as little as US $100 000, compared with $1 million or more for a standard MRI system, says Zotev. But perhaps the most exciting thing about low-field imagers is that they can also perform another imaging technique, magnetoencephalography (MEG), which, conveniently, also relies on SQUIDs. MEG measures the magnetic fields produced by brain activity and is used to study seizures. Putting the two imaging modes together could mean matching images of brain activity from MEG with images of brain structure from MRI, and it might make for more precise brain surgery.

Low-field MRI has other advantages, says John Clarke, a physicist at the University of California, Berkeley, who uses a single-SQUID MRI device to image tissue samples. "I'm personally quite excited about the idea of imaging tumors" with low-field MRI, he says. The difference between cancerous and noncancerous tissue is subtle, particularly in breast and prostate tumors, and the high-field strengths used in conventional MRI can drown out the signal. But low-field MRI will be able to detect the differences, Clarke predicts. A low-field MRI might also allow for scans during surgical procedures such as biopsies, because the weaker magnetic field would not heat up or pull at the metal biopsy needle.

Groups in Europe and Japan are also developing low-field MRI, both for identifying tumors and for matching with MEG. Zotev is working on improving the image quality, perhaps by increasing the strength of the prepolarization field, and studying what signals might be read in low-field MRI that conventional MRI might miss. He says that, with enough focus on the engineering issues, practical devices might be ready for clinical trials within a couple of years. —NEIL SAVAGE

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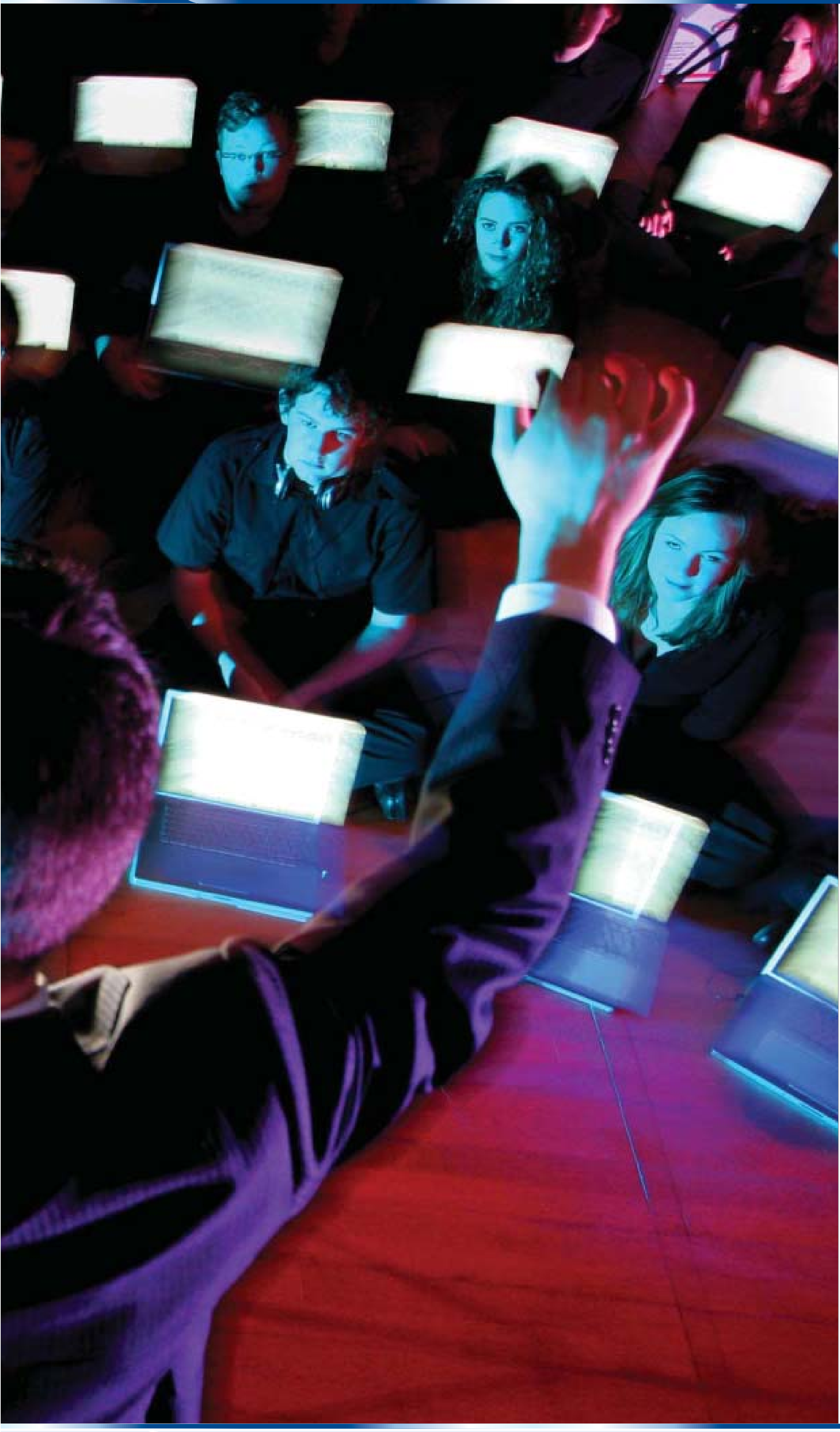

the big picture

LAPTOP ORCHESTRA

In November, 50 music students from the University of York, in England, played their first concert as the world's largest digital orchestra. Ambrose Field, the director, calls his Worldscape Laptop Orchestra "a vast, humanly controlled synthesizer." The ensemble combines drummers, DJs, and classical violinists to modernize the traditional orchestra. The musicians produce a range of sounds by typing commands and by sweeping their hands in front of a camera inside the laptop, which translates the movement into sound. As the students perform, algorithms follow the music and drop in new sounds.

PHOTO: LORNE CAMPBELL/ GUZELIAN

reflections *By* ROBERT W. LUCKY

Technical Publications and the Internet

IT'S A joy to search and access information so effortlessly on the World Wide Web—that is, until I'm looking for a technical publication. Far too many are hidden behind subscription and payment mechanisms.

The great irony is that virtually every technical paper is held on the computer of an author who would be thrilled to send a free copy to anyone requesting it. But requesting every paper that you might (or might not) want is so inconvenient that almost no one does this. So why aren't all technical publications freely accessible on the Web?

GREG MABLY

The first argument that comes to mind is that institutions must restrict their publications to their members to keep those members. However, I doubt that people join the IEEE, for instance, to receive the *Transactions*—even though many of them say they do in surveys. I would contend—based on no hard data whatsoever—that engineers join to enhance their sense of professionalism and that very few read the *Transactions*. That doesn't mean that its papers have little importance, only that the information they contain is primarily promulgated through social networks. Let me be clear that I'm speaking only about heavily technical material and that there are many other publication formats that should indeed be reserved as member benefits.

There are a number of other arguments against free access to technical publications, including the revenue that libraries and publications bring to the institution. I can only say that although these are problems, I have neither the space here nor the relevant knowledge to address them. A more curious barrier is the attitude of the authors themselves. While every author wants as many readers as possible, it seems we are conditioned to want to see our work in print. A work that appears only on the Internet doesn't seem to have the same weight. Perhaps that is why we call them papers.

The Internet community has been inventing new ways to convey information and to collaborate in understanding it—consumer reviews, discussion forums, blogs, community filtering, and the Wikipedia model. Perhaps we in the technical institutions haven't taken full advantage of these ideas, and it may be that our historical model for publication is what's stopping us.

An interesting experiment that has come to my attention is a new policy called publish first, review later. The idea is to cut out the months-long process of review and publication, which seems less and less tolerable as technology accelerates, without permanently renouncing the greatest value our institution can provide: selection among proffered materials. Can we have it both ways—quick publication without barriers *and* knowledgeable guidance about which papers are valuable?

I can only imagine how such a system might work. We might have three Internet formats—a "provisional" magazine that would contain newly submitted, unreviewed papers, a "classic" magazine that would carry only papers approved by a group of invited reviewers, and a third magazine for the dreaded "other" category. Whether the formats would allow for "consumer" reviews and discussion is an interesting question.

The system would speed publication and stimulate discussion, thus providing more feedback to authors. However, the public scrutiny might discourage many aspiring authors, who would fear the ignominy of having their papers panned, then demoted to the "other" category. There is also the question of whether a paper could be modified or withdrawn. Are our papers living documents or are they to be inscribed in immutable stone?

I realize that I have raised more questions than answers. Like many of you, I am both an occasional author and a consumer, and I'm not even sure of what I want in either instance. I just feel we can improve on the system we now have. ❏

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"When you learn how to fly F-16s, you get basic radar theory, but I understand the actual math and aerodynamics behind it." —ROBERT RICKARD, TEST PILOT AND CONSULTANT

careers

ENGINEER TURNED JET JOCKEY

On a doctor's advice, an EE decided to become a fighter pilot

WHEN ROBERT "Bobaloo" Rickard was growing up, he dreamed about designing circuits, not piloting a fighter jet.

"Ever since junior high, I wanted to get a degree in electrical engineering," he says. "But when I took my Air Force physical, the doctor said, 'Why do you want to do that as a career? Pilots are the focus.'"

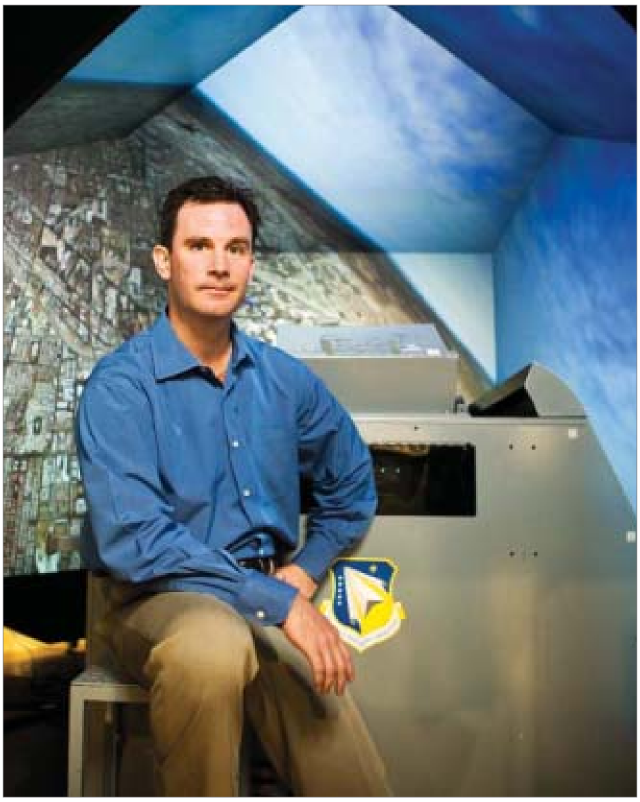
The University of Missouri-Rolla electrical engineering student was on a scholarship from the Air Force Reserve Officer Training Corps at the time. Of the 26 ROTC students that year, only two got pilot slots. "And the only reason I was one of them was because the doctor had talked me into it," Rickard says.

Of course, an unsuspected knack for the job may also have played a part. After finishing pilot training, Rickard got assigned to fly F-16 fighter jets. He spent 13 years on active duty, logging more than 100 hours over Iraq in the mid-1990s, between the Gulf and Iraq wars. He twice earned the title Instructor of the Year, and in 1999, he was one of just 20 F-16 pilots sent for advanced training at the U.S. Air Force Weapons School—the Air Force version of the Navy's Top Gun school, made famous by the movie of that name.

"It was by far the hardest thing I've ever done," he says. "It's like getting a Ph.D. in fighter pilot. You become the instructor to the instructor pilots, and it sets you apart for jobs."

In 2003, at 36, he left active duty and got consulting work at Vision Systems International, a San Jose, Calif., firm that employed Rich "Scöbs" (pronounced "Scobes") Scobee, an old fighter-pilot pal, as business development manager. A year later, Rickard realized that he could pay his bills doing this kind of work, so he went out on his own with the Rickard Consulting Group, of Goodyear, Ariz. Now he has 10 employees.

Like most jet jockeys, Rickard has made an art of multitasking. Take his work life as an example. He spends half his time on his company, helping private industry develop and market a variety of products—such as a pilot's helmet with computerized visor displays—and working out better ways for instructors to combine flight simulation with the real thing. Rickard expects the company to pull in nearly US $1 million in revenue this year.



GROUND SCHOOL: Robert Rickard with an F-16 simulator, which he "test flies" to make sure it teaches trainee pilots the right stuff. PHOTO: JEFF NEWTON

Another quarter of his time goes to B&D Concepts of Scottsdale, Ariz., a two-year-old outfit founded with Don A. "Dagger" Grantham Jr., an old fighter-pilot buddy. Bobaloo and Dagger, the eponymous B&D, brainstorm technical ideas, patent them, and find manufacturers to bring them to market. The advice of Rickard's father-in-law, a patent engineer for Boeing, helped get B&D off the ground, and the two pilots have taken off with it.

"I'm more the techie engineering guy; he's more the abstract, imagination genius kind of guy," says Rickard. "He asks, 'What if...?' and the tech part of me kicks in with, 'This is how we can use it.' We've been able to come up with some things that are unique and fit into the real world." One of their recent ideas—the details of which remain under wraps—

has recently sparked the interest of several space tourism companies.

Finally, he keeps his hand in flying, mostly at the Air National Guard/Air Force Reserve Test Center in Tucson, where he tests software and hardware slated for the coming year's F-16 models. "Our job is to come up with new tactics, techniques, and procedures. I actually lose money flying, because I pay myself more than the military. But I'm doing it as long as my body can take it, and it helps keep me plugged in and credible as a consultant."

So what's the story behind the nicknames? Rickard explains that the older pilots confer them on newbies in a colorfully unprintable ceremony that's "usually tied to your name or related to something funny you did, or something you screwed up while flying," Rickard says. "And this is a job where you screw up every day, so I kept getting renamed throughout the year. I had to bribe my superiors—usually it involved booze—to change my name."

In 1994, on assignment in Korea, he got the handle that finally stuck. He was playing drums in the base's house band, Steal Wool, and his buddies decided that "Rickard" sounded like "Ricky" Ricardo, who played bongos in the 1950s U.S. television show "I Love Lucy" and shouted "Babaloo!" onstage. (Dagger's handle grew out of his childhood nickname, D.A.G., based on his initials.)

"By my second tour there, in 1998, the band was still going on," Rickard adds. "As personnel arrived on base, our squad would try to get guys based on band talent. It's still playing there, and a bunch of us re-formed and play gigs around Phoenix."

Plenty of military men take engineering courses in college without a thought to practicing the profession. But Rickard's attitude was different, and it shows. "Interestingly enough, everything I do draws on my electrical engineering background," he says. "When you learn how to fly F-16s, you get basic radar theory. But I understand the actual math and aerodynamics behind it. In consulting, I'm trying to help other people make better products, so my degree gets me in the door and gives my opinions a little more weight."

He also lauds his pilot training, which after all has occupied most of his adult life. "You develop these unique skill sets that enable you to adapt to anything. If you have five fighter pilots working for you, you can run any company."

Especially if one of them is also an EE.

—Susan Karlin

tools&toys

IM DOING FINE

Instant messaging comes to cellphones at last

INSTANT MESSAGING has been a major desktop application for a decade. But it's potentially even better when you're on the go, which is why wireless carriers in the United States are beginning to offer it.

It's clear why customers would sometimes prefer IM to text messaging. Besides the back-and-forth dialogue format, you get to pick your contact from a short list of buddies instead of the longer one for all your contacts. Best of all, the buddy list shows who's online and whether they're available, a feature called "presence." Such information is already built into some corporate e-mail applications, and it's clear it will eventually make its way to all cellphones.

HELIO OCEAN
Service: Helio; Coverage: New York City—excellent; Cedarville, Mich.—poor; Keyboard: QWERTY
PHOTO: HELIO

To find out how well IM works on a tiny cellphone, I put three new and very different phones and their respective carriers through their paces, and as a further stress test, I shipped them off to a friend in Michigan's Upper Peninsula, where service can be spotty. All the phones come from Asia or are of mixed Asian-European lineage, which is interesting because IM is more important in the United States than anywhere else.

The Ocean from Helio, a cellular service that launched in May, has a distinctive double-slider design: it opens vertically to expose a typical 12-key phone keypad and horizontally to offer a QWERTY thumb keyboard. The result is a phone as heavy and bulky as any PDA, but even more useful. With more time, I would have explored the Ocean's corporate e-mail capabilities and its many multimedia options, among them the ability to upload photos directly to a MySpace page.

SONY ERICSSON W580i
Service: AT&T; Coverage: excellent; Keyboard: standard 12-key
PHOTO: SONY ERICSSON

The new Sony Ericsson W580i is one of only a few in AT&T's lineup to offer IM (for an additional US $5.99 a month). It's compact and stylish, and substantial without being heavy. It, too, has a slider design, but with only a standard 12-key keypad. As befits the Sony name, it offers several music options, including an $8.99 streaming music service called

MobiRadio. (My first song on the classic rock channel was Neil Young's "Southern Man." It's hard to argue with that.)

The Samsung Blast is lightweight, which isn't all to the good, because it feels flimsy. The slider reveals a keyboard that Samsung is very proud of. The 20 keys each bear only two letters, laid out QWERTY fashion, so that instead of having "ABC" under the 2 and "PQRS" under the 7, the uppermost-leftmost key has "QW," the next one over has "ER," and the one below it has "AS." This design can save a great number of keystrokes, but only after you've spent the time it takes to get used to it.

Conspicuous for its absence is Apple's iPhone, which lacks IM service even though its exclusive service provider is AT&T. Why AT&T would give IM capability to lesser phones but not to the single most prominent and Internet-friendly phone in the world is anybody's guess.

So how do the three stack up?

Considered purely as an appliance, the Ocean is clearly the best. It makes it easy to find and use every feature of IM—status, multiple conversations, ignore lists, and so on. It even showed my different buddy categories and let me sort by online status. I could view, or not view, offline contacts. I used the Yahoo application, but the phone also offers AOL and Windows Live.

Unfortunately, IM on the Ocean, which runs on Sprint's cellular network, stands or falls with the wireless service. That turns out to be far less than the seamless nationwide coverage that Helio promises. There was no service at all in and around Cedarville, Mich., according to Janet Haske, the technology coordinator for the local school district there and an inveterate IM user. When Haske went downstate, to Mount Pleasant, Mich., she found that even there the coverage was spotty at best. "I can see how this phone, with its nice keyboard

SAMSUNG BLAST
Service: T-Mobile; Coverage: New York City—good; Cedarville, Mich.—adequate; Keyboard: unique 20-key
PHOTO: SAMSUNG

and large display, would be good for text functions, but with no reception, none of this matters."

Haske was also less than thrilled with the Samsung Blast. "The display was hard to see in bright light, and I absolutely hated the keypad, which was very difficult to use. I'm sure I'd pick it up eventually, but for the amount of time I had it, I was frustrated." She found its connectivity to be "a little on the slow side." I, too, found it took longer to log in with the Blast than with the other phones. In addition, when I superseded my phone log-in by logging in on my desktop, the Blast didn't note that it had been logged out. On the upside, it offers even more IM applications than the Ocean.

Haske greatly preferred the Sony Ericsson phone. "Reception was great everywhere I went, even in the northernmost regions of Michigan," she said. "It's slim, easy to handle, and the keypad had a nice layout that was good for my small hands." Haske also lent the phones to her son and several of his friends when they visited her one evening: "It was the favorite of the 20-something crowd." I also liked the W580i. One downside: it carries only one instant messaging service, Yahoo's.

As is so often the case with new applications, none of the available choices is perfect. As Haske put it: "Ultimately, I want a phone that will remotely start the washing machine and coffee pot and track my significant other's Internet habits. Is there one out there like that?"

—Steven Cherry

books

PREPARING FOR THE WORST

Charles Perrow, known for his study of industrial accidents, turns his attention to terrorism

"We are not safe. Nor can we ever be fully safe, for nature, organizations, and terrorists promise that we will have disasters evermore." So concludes this important and chilling book by Charles Perrow, professor emeritus of sociology at Yale University.

Perrow is famous for his book *Normal Accidents: Living With High-Risk Technologies*, originally published in 1984. In it he argued that most major industrial disasters could be traced not to simple operator error but to the vulnerabilities of what he called complex, highly coupled systems, where each part depended on many others. He showed how small and apparently disconnected failures could cause such a system to fail catastrophically and unpredictably. So unpredictable are these systems that an effort to prevent one mode of failure may inadvertently create another one.

In *The Next Catastrophe*, Perrow argues that the United States abounds in complex systems teetering on the edge of disaster, and he wonders what might happen if terrorists were to put their thumbs on the scale. Chlorine and other toxic chemicals are stored near big cities and transported through them on poorly guarded trains; if vandals can spray graffiti on a railroad tank car filled with chlorine, what might a terrorist do? Raw milk, too, is stored and trucked about in large, poorly guarded tanks to which a terrorist could add a few grams of botulinum toxin, sickening or killing thousands of people.

The United States abounds in complex systems teetering on the edge of disaster; what might happen if terrorists were to put their thumbs on the scale?

More than half the output of a major coalfield in Wyoming crosses over a single railway bridge, whose loss would be economically catastrophic.

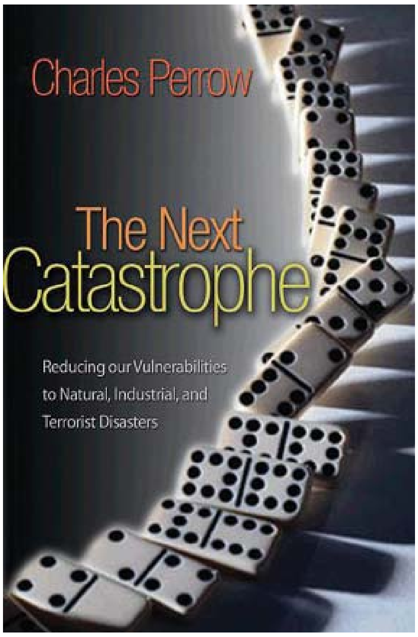
He argues that the problem is being aggravated by the concentration of economic and political power, which tends to create targets and increase the magnitude of the disasters should something go wrong. Perrow cites as an example the world's standardization on Microsoft Windows, which he compares to the dependence on a single crop, a blight on which could threaten the livelihoods of millions of people.

He also points to chemical plants, which because of economies of scale have grown to gargantuan size, storing ever larger quantities of hazardous chemicals on-site, and to the deregulation and restructuring of the electric utility industry, which has forced managers to worry more about short-term earnings than long-term maintenance. At the same time, Perrow says, government is unable or unwilling to force industry to reduce the potential for catastrophic accident.

Perrow thinks that major terrorist attacks are rare and difficult to forestall, whereas natural disasters are common and much easier to plan for. We know for sure that hurricanes will frequently hit the Gulf Coast, that trains will sometimes derail, that nuclear power plants are vulnerable to catastrophic failure, that floods and earthquakes will sometimes occur. (In the book, he calls his gripping account of a near-catastrophe in a nuclear plant "We Almost Lost Toledo.") For these reasons, he concludes, we should worry more about such disasters and less about terrorism.

And, Perrow says, the focus on fighting terrorism has increased the threats from other potential disasters. Grants that once went to train and equip first responders to disasters are now funding antiterrorism efforts of dubious efficacy, leaving a government that is at all levels less competent to plan for and respond to disasters.

One sorry example is the U.S. Federal Emergency Management Agency (FEMA), a competent agency for disaster management under the Clinton Administration. However, when FEMA was subsumed under the Department of Homeland Security (DHS) in a massive reorganization after the 2001 terrorist attacks, its focus shifted to terrorism, and it was caught unawares by the Katrina hurricane.



THE NEXT CATASTROPHE: REDUCING OUR VULNERABILITIES TO NATURAL, INDUSTRIAL, AND TERRORIST DISASTERS
By Charles Perrow; Princeton University Press, 2007; 388 pp.; US $29.95

The federal government postponed the air evacuation of Katrina victims from New Orleans, Perrow reports, until enough air marshals could be rounded up to prevent the evacuees from hijacking the planes, and then confiscated their cans of emergency rations as a security measure. Perrow views the DHS as "designed to fail," a dumping ground for political appointees, hostage to congressional pork barrel politics, staffed by dispirited employees.

While more competent administrations might improve the effectiveness of disaster-relief organizations, Perrow argues, we should not count on it. He calls instead for sweeping changes in our infrastructure to reduce the impact of future disasters. Companies should redesign industrial systems to have increased redundancy and diversification. They should reduce the size of storehouses for hazardous chemicals and shift to less toxic chemicals. He advocates closing nuclear power plants near major urban areas and moving people out of areas like New Orleans that are at high risk of flooding.

He also calls for more assessment of our vulnerabilities. "The comical effort of the DHS to do this is scandalous—allowing states to declare petting zoos and flea markets as terrorist targets," he writes. Engineers are well placed to play a constructive role in uncovering weak points in our industrial fabric. But, he continues, "technical people are unintentionally complicit in this by providing overly optimistic analyses, blaming the user, and avoiding taking responsibility for dealing with the real limitations of all systems today."

One would think that the sight of railroad cars filled with chlorine passing near the U.S. Capitol building, in Washington, would motivate Congress to take effective action. Apparently not (see "Nine Cautionary Tales," *IEEE Spectrum,* September 2006).

Perrow does not address the problem of building the political resolve to put things right. Perhaps there is no way to do it. A well-known psychological effect, called the availability heuristic, leads people to predict the frequency of an event by the ease with which an example can be brought to mind. This effect may explain why huge resources are devoted to preventing terrorism on airlines, whereas many other potential calamities are ignored. How many will have to die before government takes action?

—Kenneth R. Foster

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WINNERS & LOSERS 2008

FREDRIK BRODEN

We don't do this because we're

WHY LOSERS?

We've been asked that question many times. Everyone seems to like the idea of lavishing attention on winners, but why, they ask, use valuable magazine pages to slap around earnest, well-meaning start-ups?

It has always seemed to us that limiting our choices to winners would constrain the discussion, like studying cardiovascular health by examining only people with healthy hearts. But there's another reason, and it's related to the nature of the journalism genres that *IEEE Spectrum* has plied throughout its history.

We have always straddled technology, business, and science journalism in a way that few, if any, magazines ever have. And in those genres, articles that tout the next big thing are the mainstay. Print and broadcast media are full of stories about new technological or scientific breakthroughs that seem poised to create a giant new industry, or upend one, or in some other way change life as we know it.

mean spirited. We do it because we care

The problem is that the vast majority of new technologies fade away quietly without ever making much of an impact at all. It's a harsh reality that you'd never grasp if your main source of information were the mainstream media.

This Winners & Losers issue is our fifth. Early on, we established ground rules: we consider only specific projects that involve some element of risk and that will be introduced, or have a significant milestone, around the time our issue comes out. An entire class of technology—corn-ethanol plants in general—or a new application of an existing technology—Microsoft Windows Vista—isn't eligible.

We're particularly careful about how we select our losers. They must meet all the criteria above but, of course, have one or more seemingly fatal drawbacks. They might have negative social, economic, commercial, or environmental outcomes that outweigh their positives. A project might appear unlikely to meet its ostensible goals, or, more likely, it might seem on track to meet the goals but fail for some other reason. For example, a fuel-cell car might be an outstanding piece of engineering but fail nevertheless because it's too hard to find compressed hydrogen to make it go.

Or a project might just be plain wacky. There's a lot of that out there.

Of the 21 winners we covered between 2004 and 2007, 17 or 18 might (charitably) still be called winners. On the other hand, of the 20 losers we identified over the same period, not one has shocked us by succeeding.

Perhaps some of you are thinking that our record on losers is perfect because the declaration is self-fulfilling: by calling those projects losers, we sealed their fate. It's an intriguing idea. We'd love to believe it's true. But it's not. Senior executives, the kind with the authority to summarily pull the plug on a sizable project, very rarely make such a move on the basis of a single critical magazine article. Sigh.

From the start, we intended this issue to be part of a discussion about what makes risky technology projects succeed or fail. So we're especially indebted to Nick Tredennick, who offers his expert opinion on many of our choices in sidebars to the articles.

In the online version of our Winners & Losers coverage, you'll be able to tell us which of our winners you like best. These votes will be used to determine which of our annual winners get special recognition at the ACE (Annual Creativity in Electronics) awards ceremony, to be held 15 April in San Jose, Calif. The awards, sponsored by *EE Times* magazine and cosponsored by *IEEE Spectrum*, recognize two of our January issue winners: one for commercial promise, and another for service to humanity.

So go ahead and vote. It won't be a discussion unless you do.

—Glenn Zorpette

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WINNER: GEOPHYSICS

SOLVING THE OIL EQUATION

A team of geophysicists and computer scientists closes in on the ultimate seismic-imaging code for finding oil *By Erico Guizzo*

SUNLIGHT FILTERS through the stained-glass windows as Francisco Ortigosa wanders around the Torre Girona chapel, his eyes taking in all the details. And what details they are: there are the thick beige stone walls, the Romanesque arches, the ornately carved wooden doors, and the sleek black cabinets housing the massively parallel supercomputer.

Yep, this is no ordinary chapel. Situated on the campus of the Technical University of Catalonia, in Barcelona, Spain, this chapel has been converted into the world's most beautiful server room. It houses MareNostrum, the third most powerful supercomputer in Europe. The place is still inspiring, but these days visitors like Ortigosa come here for enlightenment not on spiritual matters but rather on the leading edge of high-performance computing.

Ortigosa is the director of geophysics at Repsol YPF, the Spanish oil giant. He heads an ambitious—and potentially stunningly lucrative—geophysical supercomputing initiative dubbed the Kaleidoscope Project. The goal of the project is to develop an entirely new class of seismic-imaging codes—the computer algorithms that transform raw seismic data into useful, detail-rich images of the Earth, kilometers below its surface. Ortigosa hopes those images will reveal oil and gas reservoirs that current codes can't uncover.

Kaleidoscope will more fully unleash the power of supercomputers like MareNostrum, which was built by IBM and has 2560 computing nodes and a peak performance of 94.21 trillion floating-point operations per second (teraflops). Today's most advanced seismic codes create color-coded three-dimensional maps of the subsurface realm by solving a mathematical construct known as the one-way wave equation, which describes seismic waves traveling in just one direction. But Kaleidoscope codes will solve the two-way wave equation, greatly improving the level of detail by taking into account waves propagating in multiple directions.

Repsol, based in Madrid, plans to use the new technology to locate hydrocarbons buried kilometers below the seafloor in the Gulf of Mexico—and below more than 2500 meters of ocean. That's what oil companies call ultradeep water, and it's the new frontier in petroleum exploration. Codes based on the one-way wave equation can't accurately image the thick bodies of salt that typically trap hydrocarbons so far down. Repsol's geophysicists are confident that two-way wave equation codes will overcome this limitation, allowing them to search for oil under 10 kilometers of sediment and hard rock where the salt bodies and underlying oil hide.

"Seismic imaging today uses lots of approximations," Ortigosa says. "Our codes will create a closer representation of the actual physics of the Earth. We're not taking shortcuts."

To carry out its plan, Repsol recruited two partners: 3DGeo, a seismic software firm headquartered in Santa Clara, Calif., and the Barcelona Supercomputing Center (BSC), which operates MareNostrum. The American geophysicists are developing the codes to solve the two-way wave equation, and the Spanish computer scientists are figuring out how to run the codes efficiently on supercomputers—MareNostrum in the immediate future and later on a BSC system based on the Cell processor, the powerful number-crunching chip developed jointly by IBM, Sony, and Toshiba.

Geophysicists have been chasing the holy grail of the two-way wave equation for years. The problem is that to even think about solving it required more than

SUBSURFACE SEER: Repsol's Francisco Ortigosa inside the glass box that houses the MareNostrum supercomputer in Barcelona, Spain.
PHOTO: FRANCISCO GUERRERO

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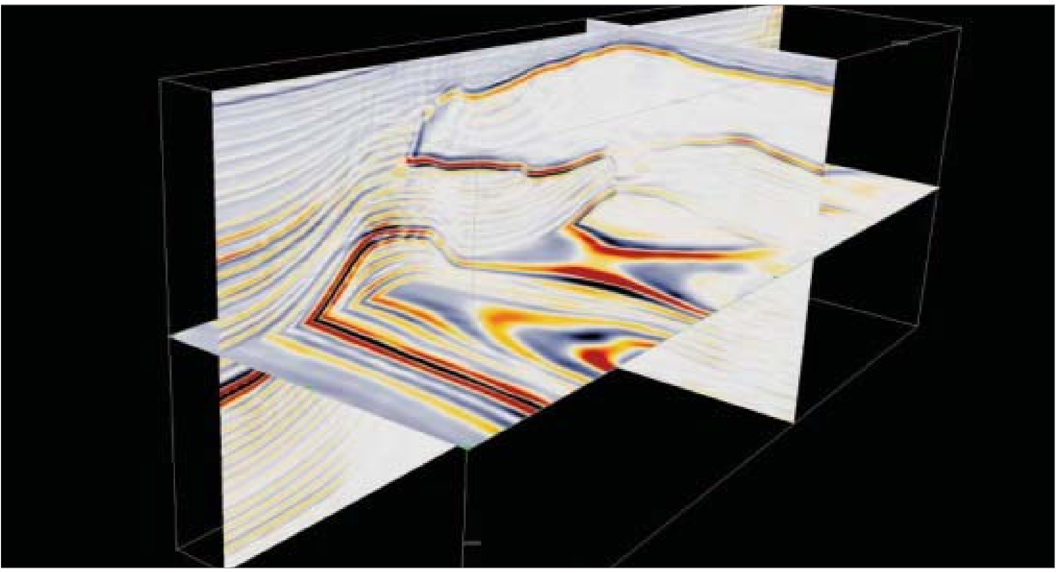

BITS AND BARRELS: A 3-D image reveals a salt dome trapping a hydrocarbon reservoir whose core area is visible in the horizontal slice.
IMAGE: 3DGEO INC./REPSOL

10 times the computing power and around 100 times the data storage capacity than was typical of available supercomputers. But more recently, rising processing power and oil prices have conspired to at last put the solution within reach.

And it's happening not a moment too soon. In the Gulf of Mexico, for example, most of the hydrocarbon reserves in the relatively shallow shelf waters have been drained. The easy oil is gone. But in deep waters there's plenty left: at least 56 billion barrels of oil equivalent—a measure that includes oil and natural gas—which at US $90 a barrel would fetch about $5 trillion and meet the entire U.S. demand for oil and gas for five years. The catch is that finding oil at such depths is extremely challenging and hugely expensive.

OIL EXPLORATION is a hit-or-miss business. Just drilling one well in the deep waters of the Gulf of Mexico to find out if it contains oil can cost $100 million. So oil companies do all they can to avoid hitting dry wells. That's where seismic imaging comes in. Better images mean less risk. So Repsol is not alone in its quest to solve the two-way wave equation.

"Every major oil company and seismic contractor is going after this," says William W. Symes, a computational seismology specialist at Rice University, in Houston, who is not involved with the Kaleidoscope Project. Access to MareNostrum may give the American-Spanish team "a bit of a leg up," he says, adding, "The main thing they've got is some very smart people with a great deal of theoretical background—and they are crackerjack programmers."

One of those hotshot coders is Dimitri Bevc (pronounced "BAY-oats"), who is president and a cofounder of 3DGeo. From the picture windows of his fourth-floor office in Santa Clara, he can see the Diablo Range, and it's a source of inspiration for Bevc, an experienced mountain climber.

But today he's pondering deeper things. He taps his keyboard and opens two large images on the screen. Each shows a cross section of a cube of earth below the seafloor, 14 km on its sides, that contains a mushroom-shaped salt body. To the untrained eye, the two grayscale images are very similar. But there's a key difference.

"Look at these vertical lines," Bevc says, pointing to the stem of the salt mushroom, where its edges merge with the surrounding sediments. In one image, created using the one-way wave equation, the stem is blurry; in the other image, based on the two-way wave equation, it's sharp. "This has huge implications in the drilling planning," he says. "Here you can't see very clearly where the target is. Here you can."

Bevc explains that oil is less dense than the sediments, so it tends to flow up through the Earth's layers. But it can't flow through impermeable salt bodies. As a result, oil accumulates in pockets resting against the salt structures. When you drill, you want to reach the top of the reservoir so that the oil flows up into your pipe. And when planning where to make a $100 million hole, you don't want a blurry image.

To appreciate how 3DGeo solves the two-way wave equation, it helps to understand how seismic imaging works. It begins with a marine seismic survey. A specially built ship cruises over an area of interest and fires an air gun that sends a powerful sound wave into the ocean. This wave propagates through the water and down through subseafloor layers of sandstone, shale, salt, and other materials, producing echoes that return to the surface. The ship tows a dozen or so cables, each up to 10 km long, carrying thousands of hydrophones that measure the minute pressure waves of the echoes. In a typical survey, the ship covers 3000 square kilometers, about three times the area of Hong Kong, and fires the air gun tens of thousands of times. Hard-disk drives on the ship record many terabytes of echo data.

Then comes the real challenge: transforming that data into images of the Earth's interior. Today's most advanced seismic-imaging codes rely on an ingenious technique devised by Stanford University geophysicist Jon Claerbout in the 1970s. Basically, Claerbout's method takes the recorded echoes, runs them through the wave equation as a mathematical extrapolation tool, and tells you the depths at which the echoes originated. With enough echoes, you can get a detailed image of the subsurface realm.

The wave equation consists of a single expression—a second-order linear partial differential equation—that describes the propagation of a wave as a function of space and time. It is commonly used not only in geophysics but also in acoustics, fluid dynamics, and electromagnetism. It can describe the behavior of a vibrating string, sound in air, waves in water, and light waves. In geophysics, the equation gives you the pressure produced by a sound wave at a specific point and time.

To solve the wave equation in three dimensions for a large volume, you need a very powerful computer. You start by creating a large 3-D grid of numbers that represent the surveyed volume of ocean and subseafloor earth. Each point in the grid stores the pressure of one or more sound waves present at that spot. Seismic-imaging codes use the wave equation to extrapolate, or "push," the echoes from the top of the grid, where they were recorded, to intermediary positions, where they originated. To keep things simple, this extrapolation assumes that the echoes traveled in only one direction: from the intermediary positions within the Earth straight to the surface—hence the name one-way wave equation.

The method worked beautifully for years in such areas as shelf waters, but geophysicists recently discovered that it can't accurately image sites with more complex geological structures, such as salt bodies buried deep below the seafloor. The reason is that the one-way wave equation doesn't account for the specific echoes ricocheting in multiple directions around those structures.

Now solutions for the two-way wave equation, which emerged in the 1980s, promise to overcome those limitations. The two-way wave equation method is different from its one-way counterpart because it accounts for cases in which a wave bounces a few times under, say, a salt dome before emerging as an echo. The two-way wave equation can retrace that propagation and thus image the area under the salt body.

The idea is to get rid of the extrapolations and instead use the complete wave equation to simulate the *actual path* of the echoes through the subsurface sediments. But how do you retrace those paths when all you have is information about the echo as it entered the hydrophones on the ship? Such a simulation would require going backward in time! The good news is, you can—in a computer, at least.

Here's how the Kaleidoscope team solves the two-way wave equation. The first step consists of getting a kind of rough model of the subsurface layers; this model is obtained from some initial preprocessing of the echo data that reveals where the waves travel faster, where they are refracted, and so on. To get a good image, you need a good initial model, so Repsol geophysicists spend weeks and even months crafting it.

Next, the 3DGeo codes use that initial model—a 3-D grid of numbers, just as in the one-way method—to propagate the echoes, each step of the wave front calculated using the wave equation running backward in time. It may sound esoteric, but all this means is that time values plugged into the equation have a minus sign. (The method is also known as reverse time migration.)

The two-way wave equation codes also need to simulate the propagation of the air gun wave through the grid. That's because you generate your image by comparing this grid of air gun data with the grid of echo data; wherever the two waves intersect, an echo originated at that point. These intersections reveal the contours and interfaces of the surveyed volume.

The Kaleidoscope codes created by 3DGeo consist of several components, written in C and Fortran, that basically solve the wave equation for each point in a spherical wave propagating within the 3-D grid. Computing each point's next step in the simulation requires about 100 floating-point calculations. For a large seismic survey consisting of 10 000 subsurface cubes, each a 3-D grid with billions of points, and requiring tens of thousands of time steps, your simulation quickly shoots up close to 10 quintillion (10^{19}) floating-point calculations. If you tried to run it on your desktop PC, it would go on for a century before you got an image like those Bevc was looking at.

MEANWHILE, AT the Barcelona Supercomputing Center, other Kaleidoscope researchers are using their expertise in fluid dynamics and computational mechanics to fine-tune the 3DGeo codes to run on MareNostrum. The machine, which comes in at No. 13 in the Top500 ranking of the world's fastest computers, has 5120 dual-core PowerPC processors, 20 TB of central memory, and 400 TB of disk storage. Built in 2005 by the Spanish government, MareNostrum resides inside a glass box at the center of Torre Girona's nave. (Latin for "our sea," *Mare Nostrum* was the ancient Romans' name for the Mediterranean.)

Other big oil companies and seismic-imaging firms probably have computers as powerful as MareNostrum—or even more powerful. They guard that kind of information as carefully as the National Security Agency would. "But those systems are busy with exploration projects, with not much time for R&D," says Michael P. Perrone, a supercomputing expert at IBM, which collaborates with the Kaleidoscope efforts. "MareNostrum lets the Kaleidoscope partners test their big algorithms."

What makes seismic imaging particularly challenging for supercomputers is the amount of data involved. The data for one subsurface cube 10 km on a

WINNER: GEOPHYSICS

TWO-WAY WAVE EQUATION SEISMIC IMAGING

GOAL: To develop advanced seismic-imaging codes based on the two-way wave equation and designed to fully exploit the power of supercomputers.
WHY IT'S A WINNER: The codes will generate images of oil and gas reservoirs in the deep waters of the Gulf of Mexico with more detail than current techniques.
PLAYERS: Repsol YPF, 3DGeo, and Barcelona Supercomputing Center
WHERE: Houston; Santa Clara, Calif.; and Barcelona, Spain
STAFF: 28 geophysicists, mathematicians, and computer engineers
BUDGET: €8 million (about US $11.7 million)
MORE: http://www.repsolypf.com

SOLVING THE OIL EQUATION

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side can reach several gigabytes, and a typical survey consists of *thousands* of such cubes. "We're working with terabytes of data, and this means that in the supercomputer we must manage the input and output of data very carefully," says José María Cela, a computer engineering professor at the Technical University of Catalonia and a BSC researcher.

SACRED SERVERS: MareNostrum, Europe's third most powerful computer, resides in a chapel in Barcelona.
PHOTO: ROLAND HALBE/BARCELONA SUPERCOMPUTING CENTER

To overcome this problem, the Kaleidoscope researchers adopted a divide-and-conquer approach. They divided the cubes into smaller chunks, each going to one of MareNostrum's computing nodes. In one test, 3DGeo divided a 10-km cube into 512 chunks. MareNostrum took about a minute to process all of them. If the supercomputer were to process the cube as a whole using one node, it would require almost 6 hours.

To speed up the codes even more, the BSC experts came up with several other strategies. They improved the codes by manually verifying the source code for tasks that could run in parallel. They minimized the exchange of data between different tasks and hand-optimized all the calculation routines. Cela says that these changes have improved the processing speed of the original Kaleidoscope code by a factor of five and at the same time reduced memory usage by a factor of two.

But MareNostrum is just a test bed for the Kaleidoscope algorithms. The goal is to develop codes for the next generation of supercomputers. Oil prospectors replace their computers as fast as you replace your PC, and maybe even more frequently—about every two years. "It's really a race," says Ortigosa, Kaleidoscope's project leader. "Before you finish coding your algorithm there's already a new hardware, and you have to start coding again."

Kaleidoscope's goal is to develop the algorithm with *tomorrow's* hardware—the Cell processor—in mind. But programming the Cell is an entirely new world for most coders. The processor's architecture—one main general-purpose PowerPC core and eight number-crunching units—is so extraordinary that it requires programmers to rethink their strategies. That's why Repsol partnered with BSC, which has lots of experience with the Cell.

In one initiative, the Spanish researchers are developing a programming environment dubbed SuperScalar, which hides the parallelization task from programmers. It allows them to develop highly parallelized code without worrying about the data flows among processors. This past November, BSC and IBM formalized a partnership to develop a new supercomputer based on the Cell. Francesc Subirada, associate director of BSC, says that nobody knows at the moment what this computer will look like. "But we do have a name for it," he says. "We call it MareIncognito."

THE KALEIDOSCOPE PROJECT had its largest software run late last year. From 3DGeo's office in California, Bevc and his team loaded their wave equation codes into MareNostrum, more than 9000 km away, and turned them loose on some echo data. Then they waited.

Twenty days later, the supercomputer completed the task. It was a simulated seismic survey. Instead of using a real ship to gather real data, 3DGeo re-created that process in a computer. A virtual ship fired air gun shots, and virtual hydrophones recorded the echoes. In contrast with the conditions of a real survey, however, 3DGeo knew the exact geology of the subseabed volume, a model provided by Repsol. The idea was to apply the wave equation codes to the simulated echoes and then compare the resulting image with the known geology to see how well the codes performed.

The area surveyed was huge: 38 km by 30 km by 15 km, representing a geological setting much like the Gulf of Mexico, with complex salt bodies. The simulation generated 32 TB of data—one of the largest synthetic data sets in the industry, according to 3DGeo. "I remember folks at BSC said, 'You cannot produce that much data,' and we said, 'Yes we can,' " Bevc says. 3DGeo considered bringing a copy to its own servers, but that much data would take two suitcases full of magnetic tapes.

Next 3DGeo used the data to test its codes. It ran both one-way and two-way wave equation codes. "We know exactly what the answer should be, so we can see if our code is right," Bevc says. The result? "It's pretty much dead on," he says. "We're able to image things [using the two-way wave equation] that we weren't seeing before, steep salt flanks and such."

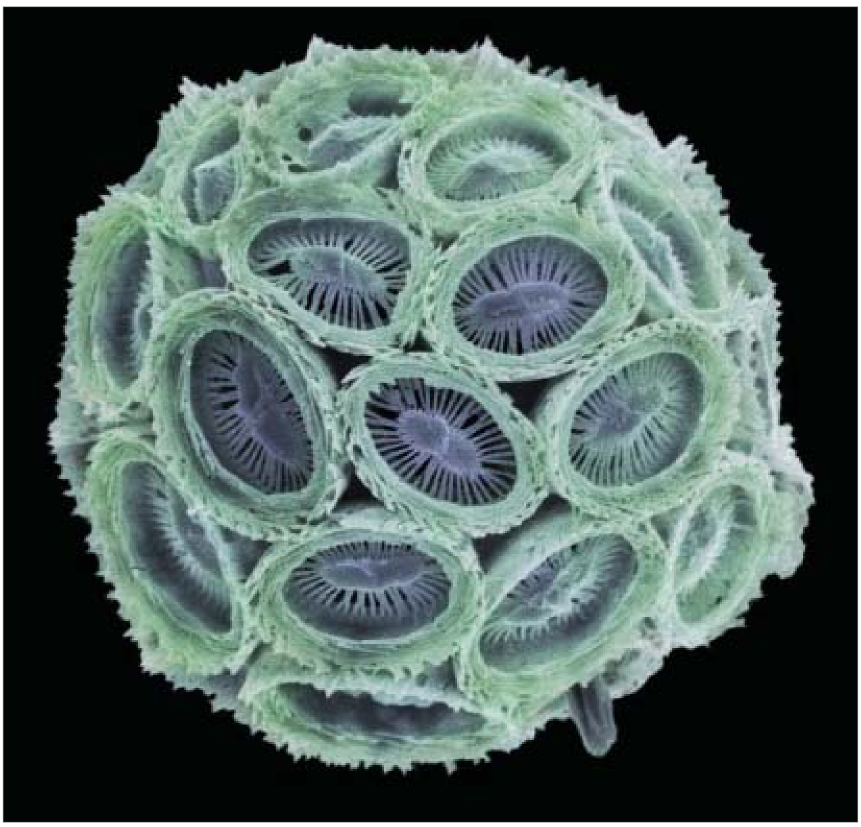
Also last year, the Kaleidoscope Project began its first production run. It involved real seismic data for a 500-km^2 area in the deep waters of the Gulf of Mexico. Repsol transported 15 TB stored in hard drives to Barcelona and loaded it into MareNostrum. How long did it take to image the area? Repsol won't say.

The company is a bit cagey about the details because it doesn't want to tip its hand to its competitors. Ortigosa says they're still analyzing the results and that sometime this year, based on those images and other inputs, the company will decide whether to drill or not. "This is real, not synthetic data, so this time we don't know the answer," he says. "But I'm confident we'll get it right." ❑

LOSER: CLIMATE ENGINEERING

ALGAE BLOOM CLIMATE-CHANGE SCHEME DOOMED

Planktos's ploy to combat global warming by sequestering carbon in the oceans holds no water *By Sandra Upson*



GREEN MACHINES: Phytoplankton, a type of algae, are at the base of most aquatic food chains. If the organisms die without being eaten, they sink to the ocean bottom. In the Southern Ocean, their growth is limited by the availability of iron. PHOTO: STEVE GSCHMEISSNER/SCIENCE PHOTO LIBRARY

As the 20th century waned and dot-com fever went critical, the flow of hallucinatory business plans became a mad torrent. Shortly before it all went down the drain, observers pointed with alarm at the millions of dollars thrown at plans for using a plastic cat to track people while they surfed the Internet, for offering virtual "sticky notes" to be attached to Web sites, and for selling a USB device that emitted odors corresponding to whatever was on the computer monitor.

Now, in the early 21st century, it seems that "green" energy and climate change are making a bid to replace the Internet as a subject of feverish fixation and flimsy business plans. And the wackiness has shifted accordingly.

Consider Russ George. He is the chief executive of both D²Fusion, of Foster City, Calif., a "deuterium solutions" company that unabashedly champions cold fusion, and Planktos, which grows forests to be sold as carbon offsets to those wishing to counterbalance their greenhouse-gas emissions. But that forest-growing business is just a sideline: Foster City–based Planktos's main goal is to spread iron dust over great swaths of the ocean, where it will feed vast blooms of surface phytoplankton that will suck carbon dioxide out of the seawater, which would later be replaced by carbon dioxide from the atmosphere.

Most recently, Planktos has nudged itself into the spotlight with its quirky plans to provide offsets, free of charge, for both Vatican City and for a newborn girl by growing separate forests in Hungary to make the state and the infant carbon-neutral. It is not clear how the baby, born last 20 August in Budapest, was chosen.

The idea behind the iron-dust scheme is that the element is the pivotal ingredient that determines how much phytoplankton can grow on some regions of the ocean's surface. Phytoplankton are the microscopic plants on which most of the marine food chain is based. As phytoplankton grow, they pull carbon dioxide from the atmosphere and convert it into organic carbon, and it's this part of the process that interests environmental engineers. The tiny plants feed marine animals, and those creatures' fecal matter sinks and gets conveniently tucked away in the depths of the ocean. Where cold fusion would have heralded an era of plentiful, free energy, now carbon extracted from the atmosphere through iron fertilization holds the promise of solving the problem of climate change.

Or at least some of it does. Oceanographers differ in their assessments of how much organic carbon actually sinks into deeper waters and how much of it is taken up by other organisms or swept along by ocean currents. Nevertheless, if iron is dumped in all the world's waters

ALGAE BLOOM CLIMATE CHANGE

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that are conducive to phytoplankton growth, "the most you could possibly sequester is about 1 gigaton of carbon per year, and that's if you wish away all the problems," says David Archer, a geophysicist at the University of Chicago who studies the carbon cycle. Other oceanographers contacted for this story agreed with that metric. That quantity, Archer estimates, would cover less than one-tenth of annual world emissions of carbon dioxide.

"If the trade-off is having to alter the biology of a big chunk of the ocean and what I get is a gigaton a year" of carbon uptake, "then I'm not interested," says John Cullen, an oceanographer at Dalhousie University, in Halifax, N.S., Canada. Others are less dismissive and see carefully conducted iron fertilization as a promising component of climate change mitigation, once ocean scientists have worked out the details—but not before then, and certainly not right now.

By design, iron fertilization would modify the biological processes at work in the ocean, and the list of potential, though unproven, side effects is long and daunting. High on that list, says Louis Codispoti, a research professor at the Horn Point Laboratory of the University of Maryland Center for Environmental Science, in Cambridge, Md., is the possibility that an increase in carbon sequestration might cause other parts of the ocean to release more nitrous oxide—a greenhouse gas that is 300 times as potent as carbon dioxide.

But it's hard to know for sure what the presence of more iron might do to the ocean because it is extremely difficult to monitor the movement of particles—over weeks let alone over decades. So keeping track of how much carbon actually sinks is at best an imprecise science. Compare iron fertilization with planting a forest to sequester carbon. Trees, just like phytoplankton, use carbon dioxide from the atmosphere. Even with forests, though, it is not at all straightforward to set up a mechanism for validating and auditing the greenhouse-gas reductions attributable to those trees. For example, depending on whether you plant a forest in the snowy subarctic or in old volcanic ash, you could increase or decrease the local albedo, which is an indication of how much heat is absorbed by the Earth's surface by virtue of the amount of sunlight it reflects. In other words, depending on where you've put that forest, it may end up soaking up more heat from the sun than that patch of land would have done without the forest, and perhaps lead to localized warming.

But all that is child's play compared with tracking carbon in a moving, shifting ocean. "You know there's a forest there. It doesn't move, and it doesn't cross boundaries. But when you're dumping iron in the ocean, you're crossing national boundaries and potentially producing changes in other people's ecosystems," notes Anand Gnanadesikan, an oceanographer at the National Oceanic and Atmospheric Administration's Geophysical Fluid Dynamics Laboratory, in Princeton, N.J.

In a press release, Planktos announced that its research vessel, the *Weatherbird II*, entered international waters in early November, sailing along a secret route to an undisclosed destination in the equatorial Pacific. It's open knowledge, however, that Planktos has had its eye on a patch of water off the Galápagos Islands as a test site for a large-scale fertilization. (The company did not respond to requests for an interview.)

The firm contends that the amount of plankton has dwindled and that the offsets will restore it, a claim that some ocean scientists take issue with. "It shouldn't be sold as a solution to a problem, when there isn't any agreement that the problem exists," says Ken Buesseler, a senior scientist at Woods Hole Oceanographic Institution, in Massachusetts.

Buesseler notes that carbon offsets are basically unregulated, which has made it relatively easy for environmental entrepreneurs to take advantage of a lax legal framework. Several organizations have suggested that standards are needed to fill the regulatory void and to serve as checks on carbon-offset providers. Without the support of scientists—and those contacted for this article did not know of any experienced ocean scientists with a high-level affiliation with the company—Planktos's offsets are unlikely to gain much popularity. According to Andy Dvoracek, a senior client manager at Dublin-based Ecosecurities Group, a company that helps other businesses reduce and trade their emissions, very few methodologies for carbon-sequestration projects have been approved in protocols such as the Voluntary Carbon Standards, developed in part by the International Emissions Trading Association, in Geneva. So far, none exist for iron fertilization. "Sequestration-type projects are a very controversial space," Dvoracek says.

So much so, that even the oceanographers themselves can be chary. To attend a conference on iron fertilization at Woods Hole in late September, Archer decided to fly in from Chicago guilt-free. "I told people that I'd bought offsets for my plane tickets to go there, and everyone sort of laughed at me," Archer says. "If iron fertilization becomes commercial before it's proven to work, it'll poison the whole notion of carbon offsets." ❑

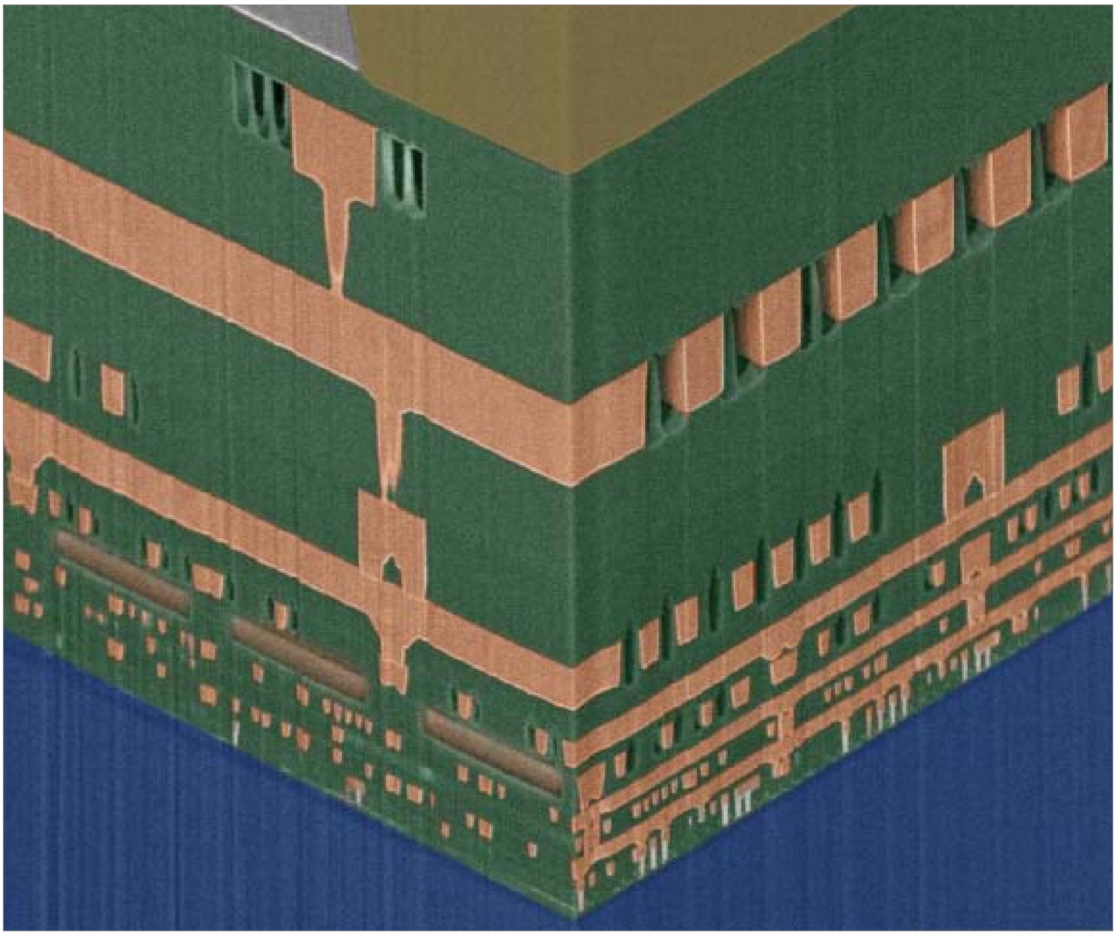
WHAT THE EXPERTS SAY

"Carbon credits are the modern equivalent of papal indulgences. Planktos intends to profit from guilt generated by purveyors of ecoscares. It has attained a hubristic acme in asserting that its seeding of the oceans with iron dust to sequester carbon dioxide is 'eco-restoration.' It is a good thing plants are unable to organize a counter-campaign to sequester oxygen." —Nick Tredennick

LOSER: CLIMATE ENGINEERING

OCEAN FERTILIZATION FOR CARBON SEQUESTRATION

GOAL: To combat climate change by stimulating phytoplankton growth, so as to soak up carbon from the atmosphere and eventually bury it in the deep ocean.
WHY IT'S A LOSER: There is no good way to monitor how much carbon is sequestered or what downstream effects the added iron may cause.
PLAYER: Planktos
WHERE: Foster City, Calif.
STAFF: 12
BUDGET: Info not available
MORE: http://www.planktos.com



HOLES: IBM'S air-gap technology carves nanoscale holes into the insulation between a chip's copper wires, as seen in this electron micrograph.
PHOTO: IBM

WINNER: SEMICONDUCTORS

THE ULTIMATE DIELECTRIC IS... NOTHING

IBM packs wires in vacuum to speed chips and save power *By Sarah Adee*

THE RUNNING JOKE at IBM's site in East Fishkill, N.Y., is that engineers who have been working there for 30 years still have trouble locating their own offices. And sure enough, finding your way through the low hedge of cubicles in the 300 Building is very nearly impossible. That's because the architect designed it to reproduce the tortuous wiring scheme inside a microprocessor. That's the rumor, anyway.

Now imagine having to insulate such a tangle, but in microcosm: many kilometers of nanometer-scale copper conductors in a sliver of semiconductor the size of a child's thumbnail. That was the challenge facing IBM Fellow Dan Edelstein, who 10 years ago led an industry-wide switch from aluminum to copper chip wiring that has enabled every microprocessor since 1998. Now Edelstein is hatching his next revolution. With his colleague Satya Nitta, he is surrounding the conductors in IBM's bleeding-edge microprocessors with holes. He thinks his competitors will have little choice but to follow his lead in the infinitesimal realms he is staking out.

Those holes—IBM calls them air gaps—are actually cavities of vacuum embedded in the insulation that surrounds the chips' wiring. Air gaps may well be the solution to a problem that has been tripping up chip manufacturers for almost a decade: when you cram nearly 10 kilometers of wiring into a space smaller than a postage stamp, the signal on one wire is felt by its neighbors. The electric field between them can then impede the flow of current through the wires, and that slows down the signals they carry.

IBM is a bit cagey about saying exactly when the new technique will go into production, other than that it will be in chips slated for production in 2009. Sources familiar with the technology, however, say there's

ULTIMATE DIELECTRIC

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a chance that it might go into production sometime this year.

The advance, like so many in the industry, comes not a minute too soon to prop up Moore's Law, which insists that transistor density will double about every 20 months. That's how Intel got from its 33-megahertz 486 processor in 1989 to its 2.9-gigahertz Xeon processor in 2007.

Ever since the microchip was invented, the basic rule of thumb has been that transistor size is the limiting factor on chip speed. "Transistors are the fluke of nature," Edelstein explains. "They get faster when they get smaller, but nothing else does." A microprocessor may have hundreds of millions of transistors, but no matter how fast those transistors get, they depend on wires, which get much slower when they get smaller. That's a problem for the transistors, which must compensate by using more power. It's also a problem for the wires, which must radiate heat from the extra power the transistors are using.

As it turns out, the source of the signal lag is not so much the metal interconnects themselves but rather the insulation between the wires. So the question of the moment is, what can you put between those wires to prevent the signal from leaking?

Vacuum is the best insulator known. Since the 1990s, many chip manufacturers besides IBM, including Infineon Technologies, in Munich, and STMicroelectronics, in Geneva, have experimented with vacuum cavities, and some have even built prototype chips. But two problems have kept the technology from entering production. A chip needs insulation to shield its wires from one another, but it also depends on that insulation for structural support to survive what can be a rough manufacturing process, as well as the often high temperatures on a printed circuit board. Fill the insulation with holes, and the whole chip might collapse. The second problem is making air gaps compatible with standard chip-fabrication techniques. Despite the performance gains that companies have realized on their test chips with air gaps, added equipment and exotic materials have canceled out the performance gain with a money drain.

But the state-of-the-art chip IBM unveiled back in May could usher in the era of vacuum. "The technology is quite impressive and innovative," says James Meindl, a director of the Microelectronics Research Center at Georgia Tech. "It's structurally sound, and IBM's design has reduced the signal lag enough to "buy back" between 10 and 15 percent of chip speed that would otherwise be lost. That performance boost is about what you get from doubling the density of a chip's transistors, and IBM did it without exotic materials, new tools, or costly redesigns. "It's a very straightforward process," says James Watkins, codirector of the MassNanoTech Institute at the University of Massachusetts in Amherst. "It stands a good chance of being mainstreamed."

The industry has been insulating microchip conductors with silicon dioxide (glass, basically) since the first commercial integrated circuits were introduced in 1961. For years, the wires that carry the electrical current on a chip were barely an afterthought. "The transistor was everything," says Edelstein.

But by 2000, joining the millions of transistors into a functioning integrated circuit necessitated nearly 2 km of wire. Nobody wants wider chips (space on a circuit board is always tight), so the only way to pack in all that wiring is to make them taller. To do that, individual wiring levels—each consisting of the glasslike insulating material inlaid with a network of the copper wiring—are stacked on top of each other by a process called dual damascene, named for the ancient Middle Eastern method of inlaying gold or silver into a sword.

To build the stack, the base level—the dinner-plate-size wafer containing the transistors—is first covered with a layer of insulation made of an impure glass variant. A pattern is transferred onto it by photolithography, which is similar to photography: the insulation is covered with a light-sensitive material called a photoresist, onto which a pattern is projected, using ultraviolet light streaming through a mask. When the light hits the exposed areas of the photoresist, it changes the material's chemical properties: the area in the mask's shadow remains strong and corrosion resistant, but the area exposed to light has become vulnerable. A corrosive plasma eats away the vulnerable areas and the insulation beneath, creating a network of trenches.

Now this level is ready for its wiring. First, the glass is lined with a thin, corrosion-resistant film. Then the trenches are filled with copper. The wafer is scoured and polished to a flat surface, until the only metal that remains is inside the trenches. The result is a glassy surface inlaid with many meters of glittering copper canals.

The last step is the application of a capping layer of organosilicate—silicon dioxide that has been impregnated with carbon. This layer separates the levels from each other and provides added structural support. Then the process starts anew. Today's state-of-the-art chips can have up to 10 of these levels. But they are not strictly identical. Instead, they gradually increase in thickness, so that the lowest level of wiring is smaller and more delicate than the topmost level by a factor of eight. At the higher levels of the chip, the insulation is thicker and the wiring more substantial.

WINNER: SEMICONDUCTORS

IBM'S AIR-GAP TECHNOLOGY

GOAL: To find a way to use vacuum to insulate microchip wiring.
WHY IT'S A WINNER: Other companies have been trying for years, but IBM made it work.
PLAYERS: IBM
WHERE: East Fishkill, N.Y.
STAFF: 8, working for 4 years
BUDGET: Info not available
MORE: http://www.research.ibm.com

BUT THIS PROCESS no longer suffices. There's too much drag on the signal traveling down the tiny wires. The culprits are capacitance and resistance. Long, thin wires have more resistance, of course, than short, thick ones. So you can't do much worse than a nanoscopically thin collection of wire segments that would span a small town if laid end to end. Think of trying to suck a drink through a 2-meter-long cocktail straw. This is why the industry abandoned aluminum for copper wiring—its greater conductivity overcame the resistance of thin wiring.

The other—and bigger—problem is capacitance. When wires are cramped so closely together, the electric field from one wire is felt by neighboring wires, and that creates an unintended capacitor. A capacitor stores electrons, somewhat like a battery. Storing electrons is great for batteries, but it's bad when those electrons need to get somewhere else. Picture the electrons traveling down the wires in waves. The capacitance in the wire acts like a breaker, damping the waves' motion and therefore slowing the rate at which the signal can travel from one end of the wire to the other.

A transistor on a digital chip is just a switch that operates at incredibly high speed—2.7 billion times a second in the current generation of microchips. The higher the capacitance between the wires, the more power the transistor needs to operate at that speed. The result is power drain. Reducing capacitance lets the chip use less power to switch at the same speed.

Making the wires thicker isn't an option, so the only solution is to improve the insulator's dielectric constant, a measure of the insulation's ability to concentrate an electric field. The dielectric constant is usually referred to simply as k. The lower the k-value, the better the insulation.

The lowest possible k-value is 1.0, and the only way to achieve that number is with the ideal insulator: vacuum. Natural glass has a k-value of 4.2. When that started to become a problem, researchers began pushing that number lower by "doping" their silicon dioxide—mixing the glass with other elements, like fluorine and carbon. For decades, chip manufacturers have been groaning under the strain of pushing the dielectric constant from 4 to the mid-3s (fluorinated silicon dioxide) to the high 2s (silicon dioxide with severe carbon doping). The problem is that loading the insulator with carbon also changes its density, making the material softer and weaker. Insulation will tolerate only so much doping.

By figuring out how to use vacuum, IBM shot the industry-leading dielectric constant from a spongy 2.7 to an eyebrow-raising 1.9. The resulting microprocessor leapfrogs a full generation in total chip performance without a chip redesign.

SO HOW DO you make bubbles full of nothing? There are two ways to make air gaps, and how IBM makes them depends on where in the chip the gaps need to go. For higher levels, the spacing between the wires is less critical, so the vacuum pockets can be carved conventionally—with masks, ultraviolet light, and plasma. As usual, after the interconnect pattern is projected onto the insulation, plasma digs out the channels, and the wiring is laid. That process is then repeated to carve holes into the insulation around the wiring. The level is capped off with organosilicate in a vacuum chamber and, voilà, air gaps. The organosilicate cap layer remains, holding the wiring in place at the top and bottom, but the carved-out spaces between the wires are empty.

This strategy doesn't work at the lower levels, because the tiny spaces between the wiring don't tolerate the slightest error. At the lowest levels of the next-generation chips, the width of the insulation between wires is about 50 nanometers. Not even the best production processes can create holes inside features that small without nicking the wiring. Thus exposed, the copper would melt under the extreme heat of the plasma and leak through the air gap, fuse with neighboring wires, and ruin the chip. Conventional techniques simply can't ensure enough precision. Edelstein and Nitta had to invent a different way to make the really, really tiny holes.

They turned to organic chemistry, and their own version of something called a block copolymer. A polymer is a long chainlike molecule, and in a block copolymer, the links of the chain are repeating blocks of two different chemicals. Imagine a string of Christmas tree lights that, instead of being randomly distributed, are grouped so that a bunch of red bulbs is followed by a bunch of green bulbs, which is followed by a bunch of red bulbs, and so on. SBS rubber, used in shoe soles and tire treads, is such a substance.

But IBM's block copolymer assembles itself. The molecules' intrinsic chemical properties cause them, upon exposure to

CHIP GURU Dan Edelstein is leading the second revolution in chip interconnects.
PHOTO: CHRIS MUELLER

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ULTIMATE DIELECTRIC

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heat, to assemble into a two-dimensional mesh of regularly spaced 20-nm cylindrical holes. Think of a sieve. The resulting substance teems with trillions of these holes—much smaller than anything you can make with light and plasma. With the chip prototype IBM demonstrated in May, Big Blue was the first to take self-assembly technology out of the lab and into the semiconductor fab.

WHAT THE EXPERTS SAY

"This is a winner. Vacuum has the ultimate "low-*k*" dielectric constant of 1.0. It's cheap, too."
—T.J. Rodgers

"The polymer is easy to use and inexpensive," says Charles Black, a researcher at Brookhaven National Laboratory, in Upton, N.Y., who developed the technology while at IBM. But the extra processing steps amount to a cost increase of about 1 percent per layer, and that will mean different things to different customers. "A high-end, mission-critical system will want these in maybe four of its layers," Edelstein says. "But for a cheap chip in a video game, you want to keep costs down." That's why the step is an optional part of an otherwise normal manufacturing process.

The process starts the usual way, with channels of interconnect embedded into a layer of glass-like insulation and capped off. But that silicon dioxide cap is then subjected to additional steps.

First, the liquid copolymer is applied. Heat causes it to assemble itself into the 2-D 20-nm "sieve" template. Ions bombard the surface, extruding those 2-D holes into long tunnels that puncture the insulation beneath, creating trillions of tiny 3-D columns.

Next, the whole thing is flushed with an acid that eats the walls between the 20-nm-wide tunnels, leaving clean cavities. The copper is unscathed because the acid attacks the insulation preferentially. The cap layer under the copper is also unscathed because the 3-D tunnels pierce only the insulation between the wires. The final step—the application of the next cap layer—leaves the perforated level sandwiched between two unbroken sheets of glass holding the copper wiring between them firmly in place. Since this all takes place inside a vacuum chamber, the sealed-off cavities retain a vacuum. The process is repeated for levels two, three, and four, until conventional methods can be used again.

The chip industry has spent years pursuing the right way to make air gaps. Though myriad ways to make air gaps exist on paper, Nitta says, most of those techniques are not realistically manufactured. "That's why our results are so much more significant," he says. "We put the chip in IBM's server, and it booted up. We even got chip performance data."

IBM's closest rival in this technology is STMicroelectronics, which has been working with air gaps for 10 years. However, ST's method works only in the high, bulky levels of interconnect.

The most common mistake, Nitta says, is using insulation made from special materials, which increases the cost and complicates the manufacturing process. Intel, for example, uses what it calls nanopore technology, in which an insulating material populated with tiny, 2-nm spherical pores approximates the benefits of vacuum. Michael C. Mayberry, director of components research at Intel, says that unlike IBM's process, nanopore technology requires no extra steps. He predicts that performance gains "will be perhaps 15 percent." That number is comparable to IBM's result, but Mayberry is skeptical of IBM's projections. "Many of the wild claims I've seen reported don't materialize," he says. To date, Intel has not demonstrated its vacuum-approximating technology on any working chips.

Not everyone thinks the extra manufacturing cost is worth the performance boost. "A 15 percent improvement does not seem that exciting," says STMicroelectronics interconnect expert Davide Pandini. He speculates that the new technology's margin of error might substantially drive down the performance gain.

Mayberry says Intel is deliberately moving away from research into air gaps because of questions about structural integrity. Some critics have seized on the concern that IBM's pocked chips won't be as physically strong as those with solid insulation.

But Edelstein and Nitta argue that their chip has been put through its paces. The air gaps are not ubiquitous. "We only put them in the critical places where they do the most good," says Nitta. The proof is in the chip's effective dielectric constant, which is not the 1.0 of pure vacuum, but rather 1.9. "We had to make the chips tough enough to survive ship shock," Nitta says. Ship shock is a way of torture testing a chip by simulating a trip from scorching Arizona to frigid Alaska. Nitta says the chips have survived 1000 such cycles without damage.

IBM is making the technology available for license by its research partners, including AMD, Freescale, Sony, and Toshiba. AMD's John Pellerin says the company is considering IBM's air-gap technology to fabricate microprocessors of the next generation, known as the 32-nm node, which is expected to debut in 2009 or 2010.

The air-gap technology is now undergoing testing on three generations of chips—the current 65-nm generation, 45 nm (which makes its debut for IBM later this year), and 32 nm. Officially, IBM is adamant that the technology will not be used before 2009. But industry analysts speculate that the company will spend the coming year trying to push the technology into the 45-nm chips.

Regardless of which generation of chips is outfitted with air gaps, Edelstein predicts that the technology will be as transformative as copper wiring was a decade ago. ❑

LOSER: CONSUMER

SATELLITE TV SOCCER MOMS WILL HATE

Sirius's car TV may be great technology, but it will drive parents crazy *By Tekla S. Perry*

THE PROBLEM WITH boffo product demos is that people might take you seriously. And they might do it long before you're sure it's a product people need or want.

As a case in point, consider Sirius Satellite Radio's Backseat TV, introduced this past fall. Sirius, based in New York City, first demonstrated satellite TV for cars at the January 2003 Consumer Electronics Show in Las Vegas. It wasn't meant to be a real product, just a conceptual demo. Terry Smith, senior vice president of engineering for Sirius, says, "We were just flexing our muscles a bit. We put it on as a technology demonstration, just to prove that bits are bits and Sirius could be an entertainment company, not just a radio company."

Then some of the automotive companies already installing Sirius Radio hardware as optional equipment saw the demos and pushed the company to get the product into production.

On the face of it, adding video to audio offerings doesn't seem like a bad idea. Today, 29 percent of the 115 million households in the United States subscribe to satellite TV, according to the Consumer Electronics Association, in Arlington, Va. That's a tempting market.

Turning a technology demonstration into a commercial product isn't always easy. In this case, the first hurdle was to develop a new modulation scheme. For the demo, Sirius had temporarily taken several radio channels off the air and given the TV broadcast all the bandwidth it needed. But a commercial product would have to fit into the Sirius network without cannibalizing the radio channels quite so gluttonously, and without making it impossible for existing satellite radio units to continue to receive the company's audio programming.

The engineers of Sirius's Advanced Development Team in Lawrenceville, N.J., got to work. Enthusiastic about the product, the company announced in January 2005 that it would launch Sirius TV in 2006. That didn't happen. "The PR got out in front of our technology a little bit," Smith says.

But the engineers really rose to the occasion. They developed an impressive new transmission technology that breaks up the video signal and combines chunks of it with each of the more than 130 radio channels that fill Sirius's allocated 12.5 megahertz of spectrum. Existing radio receivers screen out that signal as noise, but the new TV receivers recognize the signal as data and decode it.

This is an implementation of a transmission technique called hierarchical modulation, in which two streams of data are sent at a given frequency; one is given a high priority—in this case, the radio programming—the other, the pieces of video data, are assigned a lower priority. Sirius's new signal carries enough data for three TV channels at a resolution that looks fine on an 8-inch-diagonal screen. (Sirius won't say what the exact resolution is.) And it has some bandwidth

NOW SHOWING: Sirius Backseat TV rebroadcasts programming from Cartoon Network, the Disney Channel, and Nickelodeon.
PHOTO: CHRYSLER

LOSER: CONSUMER

SIRIUS BACKSEAT TV

GOAL: To provide three channels of broadcast TV to children traveling in the backseats of automobiles.
WHY IT'S A LOSER: DVD players and hard disk recorders like TiVo have given parents unprecedented control of their children's entertainment options; the last thing they want is to give up that control in the car.
PLAYER: Sirius Satellite Radio's Advanced Development Team
WHERE: Lawrenceville, N.J.
STAFF: 15 to 20
BUDGET: Info not available
MORE: http://www.sirius.com/backseattv

left over for additional applications that have yet to be determined but may include data services.

To squeeze the video into a package small enough to be transmitted on top of the radio channels without affecting their reception, Sirius engineers chose the H.264 standard for video compression but tweaked it—exactly how they changed it is proprietary. H.264 was the obvious choice. It's part of the MPEG-4 suite of standards, it's in blue-laser DVD systems, and it's used in Norway for digital TV broadcasts. A host of other countries are including the standard in their digital broadcast plans.

The engineers also beefed up Sirius's existing error-correction software to reduce dropouts and designed the system to use two antennas—one attached to the front of the vehicle and the other to the rear—to improve the system's chances of picking up the satellite signal. The team also developed a chip that implements this technology, which is being fabricated by STMicroelectronics, headquartered in Geneva. The Delphi Electronics and Safety Division of Delphi Corp., in Troy, Mich., designed and manufactures the receiver hardware.

Sirius signed agreements to rebroadcast the programming of three child-oriented TV channels—Cartoon Network, Disney Channel, and Nickelodeon. The service, now called Backseat TV, launched late last year. It debuts in 2008 Chrysler Town & Country and Dodge Grand Caravan minivans (with more car models in the pipeline) and is sold through electronics retailers as an aftermarket add-on. A Backseat TV add-on to Chrysler's rear-seat entertainment system costs US $470; the whole package, including two DVD players, two 8-inch video screens, a rear backup camera, and a one-year subscription to Sirius Radio and TV, costs $2020 for high-end models of the minivans (in which some features are already standard), more for less expensive models. In retail stores, a Sirius Backseat TV receiver, without a subscription, lists at $300. The subscription price is $7 per month, added to the $12.95 Sirius Radio subscription; you can't get a Backseat TV subscription by itself.

The engineers at Sirius are delighted to see their muscle flexing become a real product. "To be able to provide a whole new range of service on top of an already deployed consumer electronics product is really cool," Sirius's Smith says. "If you look at the amount of technology we developed, what it took to get that technology into silicon, and all the quality gates that the automotive industry requires you go through, I think we've turned this around in an impressive time."

The initial customer response seems positive, if mildly so. Mike Kane, Chrysler's director of advanced technology strategy, says that 20 percent of the Town & Country minivans now rolling off the assembly line have Backseat TV installed; for comparison, about 35 percent of buyers have purchased the DVD-only entertainment system in the past. But for soccer moms, the product's main audience, Backseat TV ain't the only game in town. And Backseat TV doesn't appear to be the game soccer moms want to play. In fact, some seem downright hostile.

"If it were free and came standard, I'd pay to have it taken out!" huffs Catherine McNiel, a mom in Glendale Heights, Ill. Adds Alma Klein, a mother and advertising executive in Oak Park, Ill.: "I can only imagine how annoying it would be to pull into the supermarket parking lot only to hear, 'No, don't turn the car off, my program's still on!' " [See more comments at http://spectrum.ieee.org/jan08/tvextra.]

Industry observers acknowledge that with so many ways to get video in the car—portable game consoles, iPods, laptops, and some cellphones, in addition to DVDs—consumers are not going to be clamoring for this product.

Says James McQuivey, an analyst with Forrester Research, Cambridge, Mass.: "The future of video in the automobile is on-demand; it isn't broadcast. Broadcast may be a temporary blip, but eventually you will have what you want to watch in your car when you want to watch it, whether it comes by shiny disk or iPod or wireless connection. You won't be watching whatever someone is willing to broadcast to you."

Thilo Koslowski, lead automotive analyst and a vice president with Stamford, Conn.–based Gartner, does not see Backseat TV as a compelling product in a world with many on-demand video options. But Koslowski commends Sirius for innovating, because innovation in satellite radio has been a pretty rare commodity for a while.

He says, it would have been a really bad idea for the company to pull the plug on the project after talking about it for so long. And Sirius did prove that, indeed, even far-out demos can come true. ❑

WHAT THE EXPERTS SAY

"Low-bandwidth satellite-video-subscription services with a small demographic, few channels, and high initial cost seem doomed to failure. On the bright side, adding video to satellite radio will permit measurement of whether losses escalate linearly or are a function of broadcast bandwidth."

—Nick Tredennick

WINNER: SOFTWARE

MAKE YOUR VERY OWN VIRTUAL WORLD WITH OLIVE

FORTERRA'S LEADERS, virtual [above, from left] and actual [left, clockwise from top left]: Robert Gehorsam, president; David Rolston, chief executive; Michael Macedonia, vice president, national security division.

SCREEN SHOT AND ALL PHOTOS: FORTERRA SYSTEMS

Forterra's OLIVE software makes the business of virtual-world environments real *By David Kushner*

"CODE THREE! Code three!" shouts a police officer over a radio. "There's been an explosion at Global Financial Trust!" It's every town's nightmare: a mysterious explosion in the commercial center. Carnage. Chaos. Plumes of deadly black smoke. On this early morning in October, the city of Palo Alto, Calif., is preparing for the worst. "This is Stanford Medical Center standing by," a hospital worker urgently replies. Doctors dash to the emergency room. Ambulances speed out front, their sirens blaring.

Fortunately, the scenario is not playing out in real life but on a laptop computer, which is projecting the animated scene on a screen in a small conference room in New York City. It looks like a video game, but it's not SimHospital. The cartoon doctors and nurses making their way around the halls are being controlled by real people on PCs across the country. These people type commands to control the movements of the characters, from the speed of their strides to the expressions on their faces. Using headsets and microphones, they converse in real time. It's all happening through just one application, for medical training, of a new software package called On-Line Interactive Virtual Environment, or OLIVE.

Developed by Forterra Systems of New York City and San Mateo, Calif.,

PLAYING DOCTOR: A simulated operating room at Stanford University Medical Center lets medical workers practice on make-believe patients.
SCREEN SHOT: FORTERRA SYSTEMS

WINNER: SOFTWARE

ON-LINE INTERACTIVE VIRTUAL ENVIRONMENT (OLIVE)

GOAL: To enable users to create their own proprietary virtual worlds.
WHY IT'S A WINNER: It turns virtual worlds into business tools.
PLAYER: Forterra Systems
WHERE: New York City and San Mateo, Calif.
STAFF: Info not available
BUDGET: Info not available
MORE: http://www.forterrainc.com

OLIVE creates virtual worlds for customers in health care, the military, and the media. MTV Networks uses OLIVE to create online worlds based on its television shows; surfers can take dips in pixelated hot tubs with bikinied beauties from the Virtual Real World or customize shiny hubcaps on a flame-red hot rod in Virtual Pimp My Car.

But most of OLIVE's applications are available by invitation only, primarily for the purpose of training staff. The U.S. National Institutes of Health is creating a world that tests industrial workers' skills at responding to emergency disasters—think guys in hazmat suits wandering through toxic sludge like something from *Doom*. Retail chains use OLIVE to run employees through mock scenarios. In one demonstration, a new cashier inside a virtual surf shop has to cool down a hotheaded customer (operated by a corporate trainer) by choosing the right mix of body language and dialogue.

"There's a generation coming into the workforce that sees nothing unusual in a world unfolding on a computer screen," says Steve Prentice, vice president and director of research for Gartner Research, a technology research firm based in Stamford, Conn. "Also, complex environments are becoming more critical, and the cost of staging real-world simulation training exercises is escalating."

Investors are taking notice. Virtual Worlds Management, a tracking firm in Austin, Texas, says that technology and media firms have put more than US $1 billion into 35 virtual-world companies, chief among them Club Penguin, a children's site that the Walt Disney Co. recently acquired for $700 million. Forterra just received seed capital for OLIVE from In-Q-Tel of Arlington, Va., the strategic investment firm of the U.S. intelligence community (fittingly enough, the amount of the capital was secret).

Of all the fantasies that have emerged from the minds of geeks, none compares to the virtual world—a jacked-in, fully immersive, mind-blowing, body-rocking, computer-generated faux reality imagined in works as varied as *Videodrome, The Matrix, Star Trek, Snow Crash,* and the novels of Ray Bradbury and William Gibson. The virtual world offers escape from the drab responsibilities of work and home life. It also links up, at very low cost, like-minded people otherwise divided by the barriers of distance, occupation, and country.

"It's part of the grand quest of our species to bridge gaps and find more and more ways of connecting," says Jaron Lanier, the dreadlocked scholar-in-residence at the University of California, Berkeley, who is credited with coining the term virtual reality. "On that basis, it's a wonderfully romantic thing to do." There's just one problem: no one has yet been able to deliver much more than a cartoonish world inhabited by jerkily moving polygonal pterodactyls, accessed through clunky headsets. Virtual worlds have been excruciating, for the most part.

No one knows this better than David Rolston, Forterra's chief executive officer, who fell in love with the idea long before there was a practical way to implement it. After completing a Ph.D. in computer science and artificial intelligence and an M.S. in management systems engineering at Arizona State University in Tempe, Rolston spent years building out the early Internet. He worked on artificial intelligence for Honeywell, on software simulation for a start-up called Multigen-Paradigm (where he was chief executive), and on graphics chips for ATI (where he was vice president of engineering). He continued to nurse an interest in virtual worlds during his days at Silicon Graphics in the mid-1990s.

"We'd do demonstrations of virtual worlds, but at the end we'd say, 'By the way, you have to buy a $500 000 computer to run this,' " he says. "Then it'd get really quiet." Reason: most of the hardware capable of running a virtual world was in the hands of the military, which had invested heavily in simulation technology. So that's where Forterra went for some of its first customers—and also for some of its talent. In August, Forterra hired Michael Macedonia, a Ph.D. in computer science who had been running the U.S. Army's simulation, training, and instrumentation program in Orlando, Fla. He estimates that the military spends $10 billion a year on simulations. The simulations range from sprawling war games in the desert, with soldiers shooting laser beams instead of bullets, to one called *Full Spectrum Warrior*, in which players lead troops in realistic skirmishes.

OLIVE has its roots in There.com, a virtual-world site created by a Stanford engineer named Will Harvey and launched in 1998. In 2005, There.com spun off Forterra not to sell the virtual worlds themselves but to sell the tools with which to make them. "Rather than be a walled garden, like AOL," says Forterra president Robert Gehorsam, "we said, 'Let's create a platform that works with open standards that can be used in all kinds of areas.' "

The idea was novel, but what really mattered was the timing. By this point, Moore's Law and other forces had brought to the commercial world the necessary hardware capabilities, in the form of broadband, inexpensive graphics cards, and easy-to-use tools to create content. With that infrastructure in hand, OLIVE is all you need to make the magic happen.

ONE MAIN DIFFERENCE between an OLIVE world and other virtual worlds is the OLIVE world's "purpose-driven" intent, says Gehorsam. Rather than make the kind of free-form environment found in *EverQuest* (the massively multiplayer online game from Sony Online Entertainment, Gehorsam's former employer), OLIVE's customers want worlds that impart particular skills—like dealing with irate customers or safely disposing of bombs.

OLIVE consists of a suite of applications and tools that enable customers to build worlds accessed through PCs—up to thousands of them—that are connected through a high-speed network to five servers. The brains, called the OLIVE Core, reside on those five machines: a simulation server, which handles object simulation and interaction in real time; a communications server, which routes the simulations and communication content, such as voice over Internet Protocol (VoIP); an application server, which maintains such information as the user's account information; a database server; and a cluster management server, to facilitate software updates.

The tools are designed for a layman. For example, you can quickly fill your world with prefabricated objects that can be customized simply by changing the associated parameters—an operating table can be elongated, a closet full of uniforms can be changed to women's dresses. Changes appear on the monitor instantly. If you want to exert still more control over your world's look and feel—say, how fast a virtual cougar runs in a safari simulation or how much smoke billows up from a forest fire—you can do it by making changes within the source code of the application program interface, using C++ programming language.

The designers worked hard to give OLIVE's avatars—the computer-generated characters—gestures and inflections that are natural enough to fully involve users in the world. A customer who wants to enhance these details can employ third-party plug-ins and software, such as FaceGen, which transforms an ordinary digital photograph into a three-dimensional character. When the users communicate with one another through microphones and headsets, they can use VoIP. The audio is spatially accurate, adjusting in volume and location in proportion to the user's distance from the speaker.

The ultimate goal is to create a persistent avatar—that is, one that can move seamlessly through a sea of interconnected virtual worlds. A flight attendant in a virtual airline training exercise, in other words, should be able to simply and swiftly teleport to a NASA press conference on a simulated Mars. Forterra's chief technology officer, Jon Watte, proposes a solution: connecting existing services at the back end. "There are a lot of technical hurdles to make first the avatars, and then their inventories, move between worlds," Watte says.

One challenge is to copy information about avatars and hook that into the process of authenticating them. Another is to enable the system of one world to encode the geometry and textures of a scene into a format that makes sense to a system controlling another world. Watte says that one way to solve the problem is with Collaborative Design Activity, or COLLADA, an open standard for transferring digital assets in 3-D environments.

To transfer an avatar's identity from one world to another, system designers might modify OpenID, open-source software that provides identity authentication using a single sign-in solution for a number of sites. It's already being used by AOL and Firefox, and Watte says that with a little modification it could suit an avatar's needs too. Rolston expects to provide the ability to surf between worlds within three to five years. Meanwhile, IBM has recently announced that it, too, is working on the problem. Its partner in the effort is none other than Linden Labs, the creator of the single most popular virtual world, Second Life.

It looks as though Forterra can handle the physics, but far more important, the company seems to have figured out the customer. Michael Gartenberg, an analyst for JupiterResearch, a technology research firm based in New York City, puts the challenge in the form of two questions: "What can I do in a simulation that I can't do in real life, and what are the implications of that?"

WHAT THE EXPERTS SAY

"Generations of kids immersed for years in virtual worlds of gaming will segue naturally into professional training in Forterra's physics-based virtual-world simulations."
—NICK TREDENNICK

The answer is simple: in a simulation you can learn to drive a car without crashing, trade securities without breaking your company's bank, manage complaining customers without alienating them, treat patients without killing them. More and more organizations are working with simulations, and whoever figures out how to provide these parties with the right tools stands to do very well indeed.

Back in the demo room in New York City, for example, the OLIVE simulation is coming to a close, and the virtual patients are now on the operating table at the simulation of the Stanford University Medical Center onscreen. "I'm going to remove the shrapnel now," says the real nurse in Palo Alto over her headset, as her avatar slices into the pixels of the victim's knee. If the incision goes awry, the simulated patient may lose his leg or even his life, and that wouldn't look good, not even on the nurse's real-world résumé. But today she makes the right moves, and the patient survives. "Great work, team," the trainer says over the headphones.

"You can only imagine this 40 years from now," says Forterra's Macedonia, with a grin. "We're all going to be living parts of our lives 'in-world.' " ❑

LOSER: GEOPOSITIONING

NO PAYOFF FOR GALILEO NAVIGATION SYSTEM

Europe's answer to GPS isn't worth it

By William Sweet

BRYAN CHRISTIE DESIGN

SUPPOSE SOMEBODY offered you a free lunch at the best restaurant in Paris, Chez Gaston, complete with your favorite wine, a €500 bottle of Château La Mondotte Saint-Emilion. Would it really make sense for you to say no thanks, and then spend millions of dollars to open your own French restaurant in New York, with the stated intention of taking away Gaston's business within five years?

This, in effect, is what Europe has been doing in the field of geopositioning, a rapidly growing multibillion-dollar business that soon will dominate all aspects of transportation and navigation and is sure to play a growing role in widely disparate activities from commercial fishing to emergency services.

The idea of a European geopositioning system similar to the U.S. Global Positioning System (GPS) and Russia's Global Navigation Satellite System (GLONASS) originated a decade ago, when teams of engineers from France, Germany, Italy, and the United Kingdom developed a joint concept for an independent set of satellites that would provide superior accuracy and not be vulnerable to military cutoff. In March 2002, the European Union (EU) and the European Space Agency (ESA) agreed to proceed with the project, named Galileo, which they visualized as a public-private partnership that ultimately would pay for itself by providing premium paid services with encoded signals. Today the system is five years behind schedule and, in terms of public funding, at least a couple of billion euros over budget.

Galileo's boosters often described the system's commercial promise in extravagant terms, taking in even seasoned and tech-savvy journalists like T.R. Reid, the author of a history of the microchip. In another book, *The United States of Europe* (Penguin, 2004), Reid said that Galileo's more accurate locational signals would "trump the American effort." Due to be fully operational by 2008, Galileo would have "a four-year monopoly on the improved technology before Americans can catch up," making the €4 billion system a profit center for the EU.

That enticing vision and the rationale for developing Galileo have since fallen into complete disrepute. The original plan was to launch four test satellites by about now and, in the period from 2006 to 2010, place 26 more 700-kilogram solar-powered satellites in three orbital planes at an altitude of 23 222 kilometers. The EU and ESA were to share the costs of the four test satellites. The private sector would cover two-thirds of the costs of the remaining satellites, and total system costs would be less than €4 billion.

But by the middle of last year, it was apparent that Galileo would become fully operational at least four or five years behind schedule and that system costs would exceed €5 billion, with the private sector making little or no contribution.

Galileo's proponents said that its premium signals would provide positioning accuracy of 1 meter or better, greatly improving on the performance of GPS, whose accuracy was well above 5 meters on average at the beginning of this decade. But as early as 2004, average GPS accuracy improved to within 3 to 5 meters, and by 2012–2013 it is sure to be 3 meters or better.

There remains the question of signal access. Originally, the United States reserved the right to limit GPS accuracy for military reasons. But in May 2000, well before the

WHAT THE EXPERTS SAY

"For only €5 billion, we can get a satellite navigation system that reads out in meters." —T.J. Rodgers

"The EU's Galileo satellite navigation system seems typical of projects combining bureaucracy and government: high cost, delays, indecision, crossed purposes, conflicting national interests, and wishful thinking." —Nick Tredennick

Europeans decided to go ahead with Galileo, the U.S. president formally promised that the United States would no longer selectively degrade signals. The following years saw the blossoming of European businesses offering navigational and positional services based on the free U.S. signals, with nobody showing much anxiety about whether access to this public good would ever be denied.

With Galileo badly delayed and its commercial prospects dimming, the private aerospace consortia that were supposed to develop plans and put up money for the full Galileo fleet were unable to reach agreement: these were sprawling groups of big companies led by the European Aerospace Defense Corp., based outside Amsterdam, and Alcatel-Lucent, in Paris. In a ministerial meeting last June, it was decided to ditch the partnership and proceed with Galileo as a purely public undertaking.

Surprisingly, though the collapse of the public-private partnership sounded to many like Galileo's death knell, some hailed the change. Martin Sweeting, group chairman of Surrey Satellite Technology Ltd. (SSTL), in Guildford, England, says that proceeding on a purely public basis might help break the hold that big aerospace companies have had on procurement, opening contracting to smaller, more nimble players. SSTL designed and built the first Galileo test satellite, Giove-A, for just €26 million, on budget, on time, and to specifications—as it boasts in its corporate literature.

Giove-B, the second test satellite, being built by European Satellite Navigation Industries (ESNI), is much more expensive—its cost is now estimated at more than €100 million—and it is way behind schedule. A joint venture of leading European space companies, ESNI, in Ottobrunn, Germany, was formed to develop Galileo's infrastructure.

In March of last year, ESA contracted with SSTL to provide a third satellite, named Giove-A2, which will let Europe retain for an additional 27 months the frequency its predecessor satellite obtained from the International Telecommunication Union. If not for SSTL, Galileo would be in even deeper trouble.

SSTL may be but a small success story within a larger failure, but it's not the only one. The European Geostationary Navigation Overlay Service (EGNOS), similar to the U.S. WAAS system, is a supplementary geopositioning system that will enable air traffic controllers to replace the current system of flight corridors with point-to-point routing. Planning for EGNOS preceded Galileo, and its preoperational testing, begun in 2006, is on schedule.

Consisting of three geostationary satellites and a ground station, EGNOS transmits signals that make it possible to refine the accuracy and reliability of the existing signals from navigational satellites to about 2 meters. Japan and India have been building similar supplementary systems for aircraft navigation; eventually, airline routing based on geopositioning signals will be universal.

Still, however you look at it, the commercial outlook for Galileo is grim. The United States is steadily improving its GPS system, and meanwhile, Russian president Vladimir Putin has repeatedly said that he considers improvement of GLONASS a top national priority. Russia planned to complete the system with the launch of seven additional satellites last year, to extend its reach into adjacent regions this year, and to go global in 2009.

In light of such developments and Galileo's setbacks, the European Commission issued an important reassessment of the situation on 19 September 2007, "Progressing Galileo: Re-Profiling the European GNSS Programmes." It estimated total revenues from Galileo over a 20-year period at €9.1 billion, or €455 million per year. That suggests the system could recover its total estimated investment costs of €5.4 billion in 12 years. But standard discounting of future earnings would stretch the payback period out considerably longer, and the commission concedes that eventual earnings could be only half the amount predicted (or, alternatively, one-third more).

Despite those very uncertain prospects, Sweeting believes that Galileo will go forward, once Europe's leaders agree on where the added funds will come from, how its organizational structure can be streamlined, and where costs can be cut. But should it? Arguably, since the grand vision for Galileo has changed so fundamentally from what it was a decade ago when the project was first conceived, it now should be reconceived on a blank slate, and only then perhaps relaunched. Once seen mainly as a commercial and geopolitical competitor to GPS, Galileo should now be seen as a complement, intended in the long run to work compatibly with GPS, GLONASS, and any regional positioning system that comes down the pike. ❑

LOSER: GEOPOSITIONING

GALILEO

GOAL: To create a 30-satellite geopositioning system to provide greater accuracy than GPS or GLONASS, generating income from premium services that rely on encoded signals.
WHY IT'S A LOSER: Galileo is way behind schedule and over budget; meanwhile, GPS and GLONASS are improving, so Galileo will never obtain the competitive edge that would have made it profitable. Also, its organizational structure is too complex. To succeed, it would need a single authority with wide operating latitude.
PLAYERS: The 27-state European Union and the 15-state (not perfectly overlapping) European Space Agency
STAFF: Too numerous and too dispersed to count
BUDGET: €5.4 billion (about US $8 billion) and counting; originally €4 billion
MORE: http://ec.europa.eu/dgs/energy_transport/galileo/documents/official_en.htm

WINNER: TELECOMMUNICATIONS

SPRINT'S BROADBAND GAMBLE

A new cellular service will sell high-speed data access instead of phones and phone calls *By Steven Cherry*

THE NUMBER OF traditional telephone lines is in sharp decline, and yet people are spending more on telecommunications than ever. The reason? Their money is paying for their wireless and high-speed Internet access. The logical culmination of these trends is a single mobile broadband service that would serve your every communication need—voice and data everywhere, in your kitchen, in your car, on the beach.

The idea hasn't escaped some of the brightest minds in telecommunications. Two companies are now racing to unveil large commercial wireless broadband networks. Of the two, the one by U.S. long-distance giant Sprint Nextel of Reston, Va., is clearly in the lead: it expects to begin commercial service in three U.S. cities in April and to cover 70 million people by year's end.

But Sprint won't be the only game in town. Clearwire, a four-year-old company based in Kirkland, Wash., run by cellular visionary Craig McCaw, is aggressively converting an existing network to a mobile broadband one. The company hopes to cover another 30 million people and begin operating by mid-2008.

Negotiations that would have led to a broad operating agreement between Sprint and Clearwire broke down last fall, but the two still expect to allow roaming between their networks. Doing so will be easy; they both use the same technology, WiMax, based on the IEEE 802.16 wireless standard, in the same spectral band, 2.5 gigahertz.

The Sprint and Clearwire networks are just the sort that some other bright minds in the industry will need as they design the next generation of Internet-based communications devices. Google's so-called gPhone is just the best known of the many innovations to come.

Sprint's service, called Xohm (rhymes with "home"), will have its own operating company and brand. It will offer data rates between 2 and 4 megabits per second—better than some of the DSL and cable available in the United States. By contrast, Apple's iPhone users are stuck in the slow lane at about 50 kilobits per second. Even the latest third-generation wireless services typically run at less than 500 kb/s, less than a quarter of Xohm's speed. By blanketing entire metropolitan areas, and eventually the whole country, Xohm's mobility and ubiquity will distinguish it from that other wireless broadband standard, Wi-Fi, which is mainly used for stationary, short range, indoor connections.

If you're a certain kind of person (you probably are if you're reading this magazine), the idea of having a Wi-Fi–like connection to the Internet everywhere you go is exhilarating. Armed with a Xohm-compatible smart phone, a networking card for your laptop, or a tiny ultramobile personal computer, you could stream movies or music in real time, and you'd be able to send video and sound files too—right from your kid's soccer game, for example. It's closer than you think: Samsung, of Seoul, South Korea, already has a Xohm-ready ultramobile PC on the market, and others are expected to follow. As long as you're in a metropolitan area that gets the Xohm service, you'll be instantly and always online at high speed.

Sprint, a long-distance company that is also the third-largest wireless carrier in the United States, is not turning its back on telephony. But the service is best thought of as a broadband network that lets you make voice calls instead of the other way around, as with just about every other cellular service in the world.

Sprint spent several years testing a number of different communications technologies before choosing WiMax. Xohm's key equipment suppliers—Intel, Motorola, Nokia, and Samsung—are just a few of the many that manufacture WiMax equipment. And dozens of WiMax networks are in the works, including ones in Brazil, Ireland, and Japan. A network has been up and running in the Dominican Republic for several months.

Still, Sprint isn't betting the farm on Xohm. It will continue to sell the phones and the regular voice and data services of its existing cellular networks, which accounted for all but US $1.6 billion of the $10.3 billion in revenues the company earned last year.

But Xohm is a high-stakes gamble nonetheless. Sprint is investing $3 billion in the new network. It has committed a wide swath of expensive radio spectrum. And by offering a data-centric networking service, it is undoubtedly forgoing some revenue from voice calls, as well as from text messaging,

BRYAN CHRISTIE DESIGN

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WINNER: TELECOMMUNICATIONS

XOHM—A FULLY MOBILE BROADBAND NETWORK

GOAL: To blanket the United States with high-speed Internet access, even in a moving train or car.
WHY IT'S A WINNER: It combines the two fastest-growing areas in telecommunications: cellular and high-speed Internet access.
PLAYER: Sprint Nextel
WHERE: Reston, Va.
STAFF: Info not available
BUDGET: US $3 billion

ringtones, answer tones—just about everything that today makes a conventional cellular service profitable.

"Those are relevant to the traditional voice telecom companies, but we're moving to a completely different model," says Rebecca Hanson, Xohm's vice president of strategy. "We're creating a whole new business."

According to Jeffrey Davis, a telecom analyst at the Yankee Group, Xohm's data rates will be high enough to motivate many to discontinue their home broadband service entirely, just as millions of regular cellular voice customers have dropped their wire-line phone service. Sprint has yet to set prices, but they are expected to be comparable to landline broadband rates, which in the United States start at about $40 per month.

Perhaps Xohm's boldest gambit will be charging customers full price for the phones and other devices they'll use on the network—unlike the heavy discounts that have become standard in U.S. cellphone deals. In return, however, Sprint won't require two-year contracts, or any contracts at all. Users will be able to go month by month or even pay by the day or hour, like Wi-Fi users at an airport. You might prepay for a gigabyte of data transfers, for example, or buy a coupon that lets you upload 100 photos to your Facebook page. In fact, if Xohm is as successful as Sprint hopes, camera manufacturers—and plenty of other consumer device makers—will incorporate chip sets compatible with Xohm in their products, and you'll be able to upload those photos directly from your camera.

Eventually, Sprint officials hope to lure entire industries. For example, gas and electric companies typically build large-scale communications networks to monitor their sprawling distribution networks. According to Warren Causey, vice president of Sierra Energy Group, Xohm "offers utilities the advantage of no longer having to manage complex wireless networks."

Perhaps most intriguing of all, Xohm will definitely roil the debate, currently raging among telecommunications executives and Internet companies, about what is called network neutrality. At issue is how much control carriers will exert over the networks that we use to access the Internet. The worst possible scenario has broadband carriers like AT&T and Verizon favoring one service over another, such as Yahoo over AOL, to such an extent that the Internet in effect fractures into pieces. It would become difficult or impossible to communicate with everyone. Even in such a case, a new, neutral nationwide broadband service—which Xohm aspires to be—could provide a haven from which the entire Net would be accessible.

WHY WIMAX? At least six different standards have been floated for mobile high-speed wireless. To understand why Sprint went with WiMax for Xohm, it helps to understand where the wireless network is today, and where it's going.

Cellular carriers are at a crossroads. The convergence of the Internet and telecommunications—and in particular the carriers' transition to the Internet Protocol from older technologies designed to carry voice—is occurring very slowly for traditional wire-line networks. But analysts are generally agreed that within a decade, wireless companies will have given up these older protocols in favor of breaking up voice calls into IP packets before sending them across high-speed networks.

If the wireless future will bring a consolidation of voice and data, it may also unify the communications protocols that underlie most of today's cellular networks. Today we have two main cellular standards—GSM, by far the more popular worldwide, and CDMA, which is used by carriers in a handful of countries, including Sprint and Verizon in the United States.

In addition to these two voice-telephony standards (and a bunch of minor ones), there are several others for data, including (for GSM networks), Enhanced Data rates for GSM Evolution, the second-generation standard that iPhone users are stuck with, and High-Speed Packet Access (HSPA), a third-generation one mainly found in Asia and Europe.

WiMax, with its high data rates and reliance on IP, is generally regarded as a fourth-generation network. And by 2010 or so, it will face strong competition: a 4G cellular broadband successor to today's GSM/HSPA networks, called Long Term Evolution (LTE), should be available, with data rates at least as high as WiMax's current ones. Some CDMA carriers may also upgrade to LTE. There will be other contenders for 4G supremacy—Qualcomm, of San Diego, the inventor of CDMA, is pushing something called Ultra Mobile Broadband—but the main rivals will be LTE and WiMax.

The same basic transmission scheme underlies LTE and WiMax: Orthogonal Frequency Division Multiple Access, which is essentially what is used in the Wi-Fi (IEEE 802.11) standard as well. OFDMA has, in other words, pretty much won the field for high-speed wireless data.

If OFDMA is the new standard, the road to today's WiMax has been an unusual one in other ways. The core wireless technology, embodied in the first version of the IEEE 802.16 standard, harks back to the tail end of the dot-com heyday. It was designed for an immobile device that would sit in a home much like a DSL modem—except without needing an expensive wire or cable connecting it to the outside world. By 2004, wireless equipment makers were producing antennas and end-user devices that could exchange data at DSL-like speeds.

At the same time, though, one researcher, Hui Liu, now an associate professor at the University of Washington in Seattle, was solving the basic problems of mobile communications between OFDMA-based transceivers, such as handoffs from one cell tower to another. First at one company, Cwill Technologies in Austin, Texas, and then at another, Navini Networks in Richardson, Texas, a leading maker of WiMax equipment, Liu applied his work to the then-new fixed 802.16 standard. In early 2005, the South Korean government pushed the country's leading telecommunications companies, such as Samsung, to commercialize mobile WiMax within 18 months.

Armed with the right smart phone or laptop, you could stream video right from your kid's soccer game

Researchers elsewhere were skeptical, but by 2006, WiBro (as this South Korean version of WiMax was called) antennas were going up in Seoul and other cities. The version of the 802.16 standard that Xohm adheres to is a little different—it uses 10-megahertz channels, for example, while WiBro's are 8.75 MHz, and a number of additions have been made, including several that fall under the rubric of "quality of service"—but Korean eagerness to combine mobility and broadband speed can be credited with its breakneck development and much of the lead today's WiMax has over LTE.

Although both LTE and WiMax use OFDMA, there are some differences of course, and according to Doug Smith, Sprint's chief technical operations officer, the net result is that WiMax will be more spectrally efficient, packing more data transmission into the same bandwidth. For one thing, LTE uses a frequency-division scheme: it divides its assigned spectrum into two different channels, one for transmission and the other for reception, with a guard band between them to prevent interference. WiMax uses a single channel and divides it by time—sending, then receiving, then sending again. Frequency division is simpler, but the guard band wastes a small but precious amount of spectrum. In addition, the relative sizes of the two channels are fixed, while in a time-division scheme more time can be allocated as needed for sending or receiving.

Smith says that initially, the network will allocate about one-third of its bandwidth to uploading, that is, to letting users transmit files. That's far more than other wireless—or wired—services do. "If people are doing more downloading, then we can give even more time to it. We'll have to see how the network is used. A video blogger might upload more than download," he notes.

No one can say today just what LTE data rates will be, but we do know that WiMax does a lot better than HSPA. For a given 10 MHz, HSPA has a maximum throughput of 7.2 Mb/s downloading and 2.2 Mb/s uploading. WiMax, by contrast, gets up to 37 and 6 Mb/s, respectively.

In addition, Sprint has more of those 10-MHz segments than its competitors. It started to acquire spectrum in the 2.5-GHz band back in the heady dot-com days of the late 1990s. Coincidentally, Nextel did as well, a key reason Sprint regarded it as an attractive takeover target. It has also been swapping snippets of spectrum with Clearwire in each other's cities. All told, Xohm will have 120 MHz of spectrum in most of its markets. By comparison, AT&T and Verizon each only have about 50 MHz for their 3G networks today (which use the 1.9-GHz band).

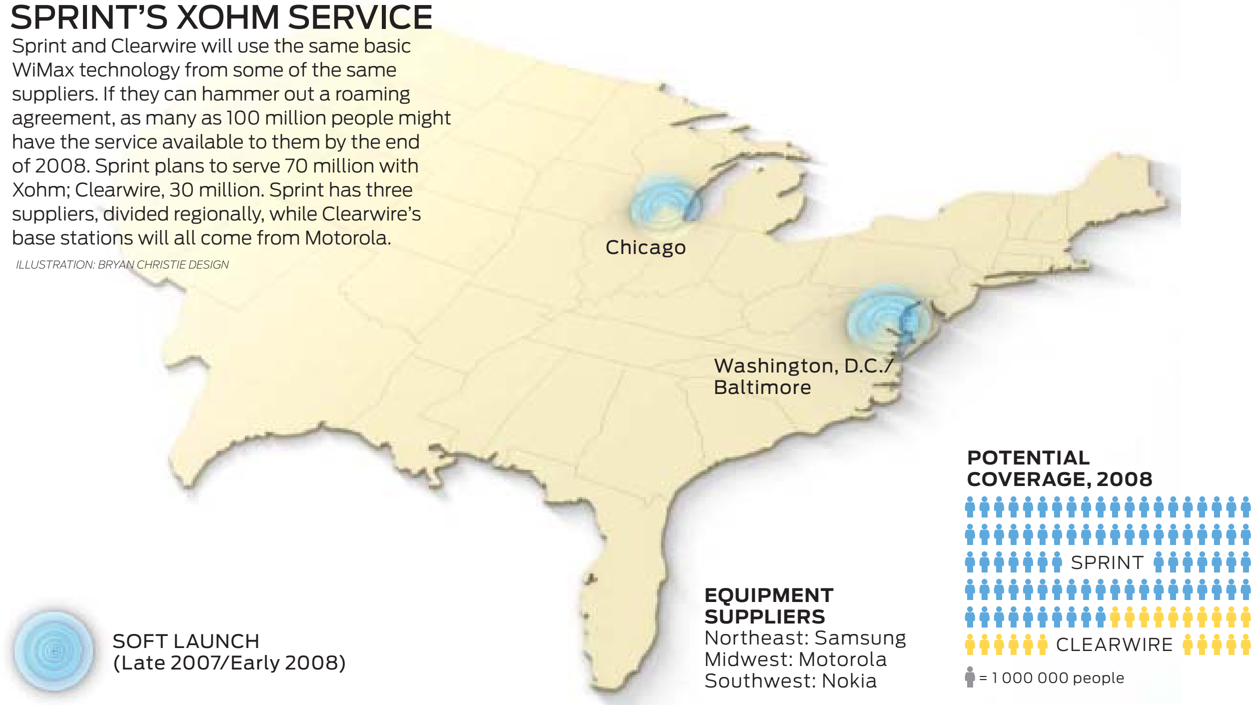
Ideally, carriers like to divide each cell into three sectors, using directional antennas that limit themselves to 120 degrees of coverage. Such a scheme is called a reuse of 3. By using a different frequency in an adjacent cell, interference at the edges, where the cells meet, is minimized.

Ali Tabassi, Sprint's vice president of technology, says that "in order to truly deliver mobile wireless broadband, one needs to have 10 MHz each for the downlink and the uplink, with a reuse of 3." A time-division transmission scheme like HSPA would need 60 MHz of spectrum to do that. That's a little more than

SPRINT'S XOHM SERVICE

Sprint and Clearwire will use the same basic WiMax technology from some of the same suppliers. If they can hammer out a roaming agreement, as many as 100 million people might have the service available to them by the end of 2008. Sprint plans to serve 70 million with Xohm; Clearwire, 30 million. Sprint has three suppliers, divided regionally, while Clearwire's base stations will all come from Motorola.

ILLUSTRATION: BRYAN CHRISTIE DESIGN



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SPRINT'S BROADBAND GAMBLE

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what AT&T and Verizon have, but it's only half of Sprint's holdings.

In the long run, LTE will have much higher data rates than HSPA. And because LTE is designed to be an easy upgrade from GSM and HSPA, it will let carriers get those higher data rates in their existing 1.9-GHz spectrum. Most GSM operators will move to LTE, so it's also likely to have a broad base of suppliers, carriers, and users—an ecosystem—from the outset. On the other hand, Xohm, Clearwire, and other WiMax-based networks will have a three-year head start in the marketplace.

Building a new network from scratch is a gargantuan task—one that, fortunately, Sprint doesn't have to undertake. For one thing, between its CDMA and other networks, the company starts with over 50 000 cell sites. Over the next year and a half, it will add WiMax radios and antennas to about 12 000 of them and create about 3000 new cell sites.

Smith insists that Xohm will be the fastest-built network in cellular history, and it just might be. Sometime this month Chicago and the Baltimore–Washington, D.C., area will get the service on a precommercial basis—a beta test of sorts. Full commercial service in those metropolitan areas is slated for this coming April. Other locales will quickly be brought online, culminating with New York City late this year. In broad terms, Sprint is working on tier 1 cities—the largest ones—while Clearwire concentrates on tier 2, places like Portland, Ore., and Grand Rapids, Mich.

Whether Xohm thrives will depend on more than just the number of people it's available to. Equally important are the services it can conjure up—including the mysterious, as-yet-undefined ones that Hanson spoke of. Of course, would-be providers of these services will want to see the millions of users first.

And it's actually a lot more complicated than that. The service providers—for example, online game companies that want to build mobile versions of their games—won't take the plunge unless they see a panoply of devices—laptop cards, smart phones, ultramobile PCs, and so on—with which users can access the network. Yet hardware manufacturers are usually reluctant to design and build those devices unless there is a big, obvious market of customers—the same customers Sprint needs to attract in the first place.

Sprint plans to break into these vicious circles within circles by assembling its own WiMax ecosystem. It has chosen three big manufacturers—Motorola, Nokia, and Samsung—to make handsets and laptop cards, as well as the radios and antennas that will go on rooftops and towers, and the routers and servers that will connect them to the Internet as a whole. Sprint has gone to extraordinary lengths to ensure that the three vendors—and a fourth, Intel—will be able to test their equipment and its compatibility with that of other companies, including cellphone makers ZyXel of Anaheim, Calif., and ZTE in Shenzhen, China. Each of the four has its own area, which it can keep under lock and key, within Xohm's own testing lab at its Herndon, Va., headquarters.

WHAT THE EXPERTS SAY

"Vertically integrated service providers will lose market share to horizontal businesses with open application environments and universal device access. Sprint's WiMax deployment will help break the users' bondage to traditional carriers."

—Nick Tredennick

Perhaps the best thing that Sprint has going for it is that Xohm is merely a focal point for a growing interest in WiMax. In October, for example, Cisco Systems, of San Jose, Calif., the router giant, bought Navini Networks. In all, the WiMax Forum claims about 500 members. In addition to Cisco, some key ones outside the immediate Sprint orbit are Fujitsu, General Dynamics, Nortel Networks, Siemens, and Alcatel-Lucent, which was shut out of Xohm but built the system for the Dominican Republic that was turned on in October. Alcatel-Lucent has contracts to build WiMax networks in Europe, Brazil, China, and elsewhere. Meanwhile, phones using Google's gPhone design may show up in the second half of the year.

As for the ecosystem of service providers, Xohm has several things going for it. First, as it is an open Internet platform, thousands of existing applications and services—Google search, instant messaging, iTunes, peer-to-peer music file sharing, you name it—will work just as they do with any other broadband connection. And according to Hwan Woo Chung, a vice president in Samsung's telecommunication systems division, the network will not only be open enough but also fast enough to allow Internet-based television and other video transmissions to flow without noticeable latency.

Sprint will probably offer voice calling on the network, but users can bring their own Internet-telephony programs—Vonage, Skype, and the others—to Xohm. These programs will work as they do on landline broadband—generally pretty well, occasionally less so. The quality-of-service provisions in the WiMax protocol let a carrier protect certain types of transmissions, giving their data packets a higher priority as they travel through the network. Sprint would of course protect its own voice packets. Doing so raises, again, the question of network neutrality, because Vonage's unprotected voice-over-IP service, for example, won't work as well as Sprint's own.

Sprint's Hanson knows this is an issue. "We're not in the business of picking winners and losers," she says firmly. "We're an open network. The more data transmitted across it, the more money we make, in the long run." And indeed, a company like Vonage, of Holmdel, N.J., could pay Sprint to protect its packets equally. If Sprint is willing to do that for any voice-over-IP provider, and similarly treats other applications and application providers, then the network will, in practical terms, be neutral.

Net neutrality will become a bigger issue only as the Internet continues to mature and as the major carriers and service providers get larger in size and fewer in number. Two months ago, AT&T announced it would use a software program to inspect the YouTube videos that its subscribers try to watch, blocking any that might infringe the copyrights of the major record labels and movie and television studios. It's just one example of how your Internet experience will differ depending on the company from which you access it—an early fracture, critics say, in the unity of the Net. Against that, a new Internet provider promising an open network—and a fully mobile, wireless one at that—will be a welcome addition. ❑

MARK PETERSON/REDUX

LOSER: SOCIAL NETWORKING

SOCIAL NETWORKING GOES TO THE DOGS

A $200 RFID dog tag tells owners—and their neighbors—when their pets are alive, at home, and sniffing things

By Sandra Upson

Burberry dog leash: US $195. Goyard collapsible dog bowl: $1970. A case of 12 cans of Pinnacle Holistic Trout and Sweet Potato formula: $19. Meeting your virtual soul mate online after walking your pooch: priceless.

The pet industry, worth about $40 billion in the United States alone, is in a growth spurt, up 65 percent since 2000. Pet products are branching out as never before in new and glamorous directions—and also in a few weird ones.

In that latter category you might put some of the many pet-oriented social-networking sites, such as Dogster. People who don't share a household with an animal might find it hard to fathom the appeal of a Web site that allows a pet owner to maintain a profile of his furry companion, along with anecdotes, a list of its friends, and of course the dog's astrological sign. (Some of these sites have an e-mail function: "Send a message to this dog.") But wait, it gets weirder.

What's missing from all these sites is the real-time element. Sure, it's fine that Rufus the bulldog is a Scorpio, but what's he doing *right now*? A company called Snif Labs, in Boston, is out to rectify this shortcoming. Snif has created a colorful little dog tag that purports to monitor a pet's activity levels, track the walking habits of its friends and enemies, and share it all in an online community, with profiles for pets and owners alike. The tag does a little bit of everything, though none of it all that well. With its accompanying base station and software, the tag will sell for $199.95.

The company's name is an acronym for Social Networking in Fur, and it began life at MIT's Media Lab. The Snif engineers are banking on a spring 2008 launch of this one product, which they contend will help neighboring dog owners to befriend one another. Basically, they have combined a radio-frequency-identification (RFID) tag with an accelerometer. The tag is battery powered and transmits its identifying code, as well as receives and stores other codes, when in range of another tag's antenna.

The idea is that when a dog goes for a walk and encounters other Snif-tagged pooches, the

LOSER: SOCIAL NETWORK

SNIF TAG

GOAL: To enable remote health monitoring and community-oriented social networking for pet owners.
WHY IT'S A LOSER: The RFID tag is not sophisticated enough to offer users practical information.
PLAYER: Snif Labs
WHERE: Boston
STAFF: Info not available
BUDGET: Info not available
MORE: http://www.sniflabs.com

tags will exchange each other's identifiers. Then, when each dog returns home, its tag transmits to the base station any codes it collected while the dog was out for its stroll. The dog's owner can check the Snif Labs online community to find out more about the dogs the pet encountered, along with information about those dogs' owners. Empowered by this data, the humans can swap profiles and declare each other virtual friends, without ever chatting in person. All this from a collar that is, as the Snif Labs Web site puts it, "hi-tech" and "hi-style."

But Jeff Clavier, an early investor in Dogster through his venture capital firm SoftTech VC, in Palo Alto, Calif., cautions that launching a successful social-networking site takes a lot more work than just signing people up—or, in this case, selling collar tags. "Once an initial community is off the ground, it's really a big challenge to get them to come back a second time, a fifth time, let alone every week," he says.

To overcome the first challenge of finding tech-savvy customers for the tag, Snif Labs is planning to target dog owners living in wealthy parts of Boston, New York, and San Francisco, according to John Gips, the company's chief technology officer. The tag and its base station will work best in modest-size apartments, where the two components will stay in more or less constant communication. The tags have motion sensors (think pedometers for pets), and when one is within range of the base station, it transmits that motion data to the pet owner's computer and to Snif's Web site. This allows owners to remotely observe their pets' activity levels—a proxy, the company posits, for overall health. Dog owners living in more spacious quarters will be out of luck unless they invest in more hardware, because the base station can pick up the tag's signal only within a distance of about 15 meters.

When set to do so, a pet's online profile can reflect when the dog is at home, by virtue of whether the base station senses a tag. The network of Snif tag owners then can see when friendly dogs or enemy hounds might be out for a walk. The company touts this feature as a way to avoid meeting combative dogs—or to track down that cute dog owner you saw the other day.

Here's one scenario: say Fifi and Rufus don't get along. Fifi's owner wants to take her for a walk, but sees on Rufus's profile that he's not home. Does this mean he's asleep in a far corner of the apartment, beyond range of the base station, or is he lurking in the park they both frequent? Fifi's owner isn't sure, so she spends the next several hours waiting for proof that Rufus is home before Fifi, too, can socialize with the right sort of dogs.

"It's expensive and a little peculiar, and my guess is that at first they're only going to get pretty weird people with a lot of money to throw around," predicts Dawn Iaccobucci, a professor of marketing at the University of Pennsylvania's Wharton School, who has been studying online social networking. "Do I really want other people to know when my dog's not home?"

Snif Labs is not the first to try to sell pet-watching products; earlier efforts have tried using RFID chips or GPS capabilities, says Michael Dillon, president of Dillon Media, a pet-industry consulting firm in Berkeley, Calif. "But they haven't done well. And remote monitoring—setting up cameras at home and so forth—hasn't caught on either. For whatever reason, it's been hard for these companies to get off the ground."

The pet items that tend to succeed either are status symbols—that Burberry leash—or they simplify owners' lives, says David Lummis, a senior pet market analyst for Packaged Facts, in Rockville, Md., a consumer goods research firm. "Usually, it's a function of what a pet needs," Lummis says. "In terms of high-tech products, things like automated watering and feeding devices have done well, because they do something really useful for pet owners who spend a lot of time away from home." Neither Lummis nor any other pet-product watchers contacted for this story had noticed much zeal for home-monitoring equipment.

That's not to say that, for the extra-passionate subsection of the apartment-dwelling pet-owning population with disposable income, watching a graph of a pet's movements couldn't become as much a part of their daily routine as checking stock quotes is for others. But a dog owner's health concerns are rarely so simple. If a dog is sluggish, an owner caring enough to remotely monitor the pet will undoubtedly notice the animal's lethargy. A really good product would provide a better read on pet health and would be both affordable and functional in spaces larger than a one-bedroom apartment. That might leave pet owners to meet each other the old-fashioned way—by saying hello when they meet in person. A social-networking site needs more than, say, several dozen dogs on Park Avenue to bring people back time and again.

It's no surprise, then, that Gips hinted the company might do better if it were folded into an existing pet-networking site. Given the strength of the pet economy, it's conceivable that Snif Labs will be bought out by a larger entity. But will the tag itself herald a new era of pet-owner synergy? We don't think so. ❑

WHAT THE EXPERTS SAY

"Who else but an engineer could imagine substituting a sophisticated computing and communications network for 'Your dog looks friendly'."
—Nick Tredennick

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PLAMEN PETKOV

WINNER: CLEAN COAL

RESTORING COAL'S SHEEN

Swedish energy company takes a novel approach to carbon capture

By William Sweet

THE INDUSTRIAL AGE, wrote historian Barbara Freese, "emerged literally in a haze of coal smoke, and in that smoke we can read much of the history of the modern world." In boom economies like India's and China's, where coal meets about three-quarters of the electrical demand, that haze still hangs heavily. Globally, according to a recent influential study done at MIT and data from the International Energy Agency, in Paris, coal accounts for a quarter of energy consumed and more than two-fifths of the electricity generated. That makes it the second leading fuel after oil and the world's main source of greenhouse-gas emissions.

You can add up all the electricity produced in the world from renewable sources plus nuclear reactors, and it doesn't amount to what coal generates just in the United States and China. It's impossible to imagine our getting along without coal anytime soon. And yet, with concerns rising sharply about climate change, the general expectation is that governments will increasingly be penalizing carbon emissions by taxing them, regulating them, or forcing companies to trade in them. So burning coal could become radically more expensive unless efficient means are found to capture and permanently store carbon dioxide, which right now is pumped into the atmosphere in astonishing quantities.

In the United States alone, according to MIT, coal-burning power plants produce about 1.5 billion metric tons of CO_2 a year—roughly a quarter of the world's total—which is about three times the weight of the total amount of natural gas the country uses each year and nearly twice the volume of oil it consumes annually.

Just capturing the carbon, not to mention finding sound ways of sequestering it, is a job of staggering dimensions and one that the world has just barely begun to address, as the MIT report emphasized. There's been a lot of talk about it, but hardly anybody is doing anything about it. "We need large-scale demonstration projects," a summary of the MIT report said, bluntly.

One company that *is* doing that kind of demonstration right now is Vattenfall, Sweden's national energy company, in Stockholm. It's building a novel clean-coal plant in southeastern Germany, in a town called Schwarze Pumpe. The approach Vattenfall will test and evaluate at the 30-megawatt facility—a technology called oxyfuel, or sometimes oxyfiring—is not the one most favored by students of carbon capture. But it appealed to Vattenfall partly because of its disarming simplicity.

In the oxyfuel process, instead of burning coal in air, the nitrogen is first extracted from the air using standard industrial equipment, so that the coal can be combusted in an atmosphere of oxygen and recycled flue gases. The result is a flue-gas stream containing almost none of the nitrogen that otherwise complicates the separation of carbon dioxide. Once the sulfur has been scrubbed using standard procedures, the flue gases consist essentially of just water vapor and carbon dioxide. The water is separated by condensation, and presto, the carbon

WINNER: CLEAN COAL

OXYFUEL PILOT PLANT

GOAL: To show that burning coal in an atmosphere of pure oxygen can facilitate carbon capture; to evaluate technical features and economics for lignite and bituminous coal.
WHY IT'S A WINNER: Because of its simplicity and its suitability for lower-grade coals, oxyfuel technology will help guarantee a future for coal in a world increasingly preoccupied with climate change. As influential voices call for larger-scale tests of promising carbon-capture technologies, this is the first such full-system integrated demonstration.
PLAYERS: Vattenfall and Alstom
WHERE: Schwarze Pumpe, Germany
STAFF: 150 to 200 at the two companies, part-time
BUDGET: €50 million (about US $73 million)
MORE: http://www.vattenfall.com/co2free

dioxide is ready to be compressed and liquefied for transport to a final storage site. In this particular case, Vattenfall will have the CO_2 trucked to a region called Altmark, where it will be injected into a natural gas reservoir, initially to enhance gas recovery, and ultimately for final disposal.

Why did Vattenfall settle on this somewhat eccentric approach to carbon capture? Back home, as Sweden's state-owned national utility, it traditionally has produced the country's electricity in hydropower stations and nuclear reactors, which for all practical purposes emit no carbon dioxide. But with the opening of Europe's electricity system to competition in the 1990s, Vattenfall began to expand outside Sweden and is more or less Europe's fourth largest electricity producer in terms of revenues.

At the end of the 1990s, Vattenfall acquired much of what had been East Germany's electricity system from West German energy companies, which had to sell them to meet competition rules. Those West German companies had already begun to improve and clean up the East German power system—which is based almost entirely on lignite—building several giant coal-burning plants, including a 1600-MW pulverized coal plant at Schwarze Pumpe.

The acquisition of the lignite plants in eastern Germany, together with the establishment of a European carbon trading system that will make emitting coal increasingly expensive, got Vattenfall's executives thinking about how to secure a future for its coal holdings and help meet commitments under the Kyoto Protocol. "The position we take is that there is a threat to the society and to the whole globe, actually. And so we need to do something," says Lennart Billfalk, an advisor to Vattenfall's CEO and the former manager of its R&D program.

Vattenfall is building the oxyfuel pilot plant at Schwarze Pumpe in close cooperation with the French firm Alstom Power, which is supplying almost all the major components except for the oxygen-nitrogen separator, the desulfurization system, and the condenser that will remove the water, leaving CO_2.

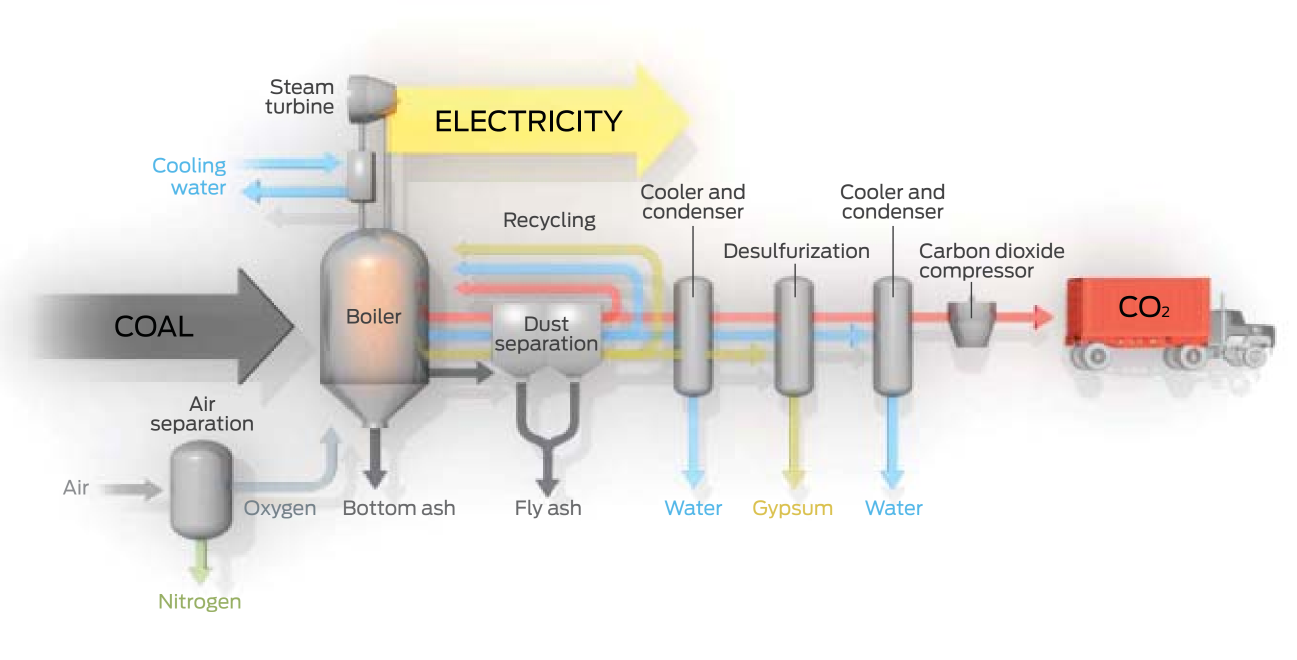
Best known for its supersleek and very fast TGV trains, Alstom, based in Levallois-Perret, is the world's No. 2 transportation company and No. 3 in power generation, behind GE and Siemens. The company sees oxyfuel as a growth opportunity and the Schwarze Pumpe project as a learning experience, says John Marion, vice president for global technology at Alstom's U.S. power subsidiary in Windsor, Conn. Marion says that Alstom has been looking closely at oxyfuel and that the Schwarze Pumpe project is the "most significant and advanced step globally" in the field of coal power with carbon capture. He adds that the company has been looking closely at oxyfuel prospects since 1997, because of Kyoto.

A quirky but important aspect of the Schwarze Pumpe plant [see diagram, "Just Take Out the Nitrogen"] is that flue gas is recirculated back into the combustion chamber in order to keep burning temperatures close to their levels in a regular coal-fired plant, near 1000 °C. Research engineers originally devised this procedure when oxyfuel combustion—which, by the way, is common in other industries such as steel, aluminum, and glass—was first visualized mainly as a retrofit technology for existing coal plants. If coal were burned in pure oxygen without recirculation, temperatures would get high enough to melt boiler walls. Recirculating the flue gases simulates, in effect, atmospheric burning conditions, with carbon dioxide substituting for nitrogen.

When a plant like the one at Schwarze Pumpe is custom designed, recirculation is theoretically not necessary; the boiler could be designed to withstand higher operating temperatures, and higher-temperature combustion could produce efficiencies. But the Vattenfall and Alstom designers wanted the boiler to be as similar as possible to standard boilers so that they could make close comparisons and scale up with greater confidence, says Marion. Also, coal typically contains between 5 and 30 percent ash, and if the ash melts in excessively high temperatures, it gets sticky, glasslike, and hard to handle.

Alstom would like to be able to sell utility-scale oxyfuel plants—not just major components—on a turnkey basis with the usual full guarantees by the middle of the next decade. And Vattenfall, too, would like to move aggressively with oxyfuel and have a precommercial plant in the 250- to 300-MW range running by 2014 or 2015. Right now Vattenfall is evaluating seven larger carbon-capture projects in Denmark, Germany, and Poland and expects soon to select two, one of which is likely to be an oxyfuel plant. The company's economic target is to develop plants that will pay for themselves if carbon prices in the European cap-and-trade system stabilize at €20 per metric ton or higher.

The oxyfuel concept for coal-fired power generation originated in the late 1970s at Argonne National Laboratory, near Chicago, according to Alan Wolsky, the leader of the team that pioneered the idea there. Wolsky, now a visiting fellow at the University of Cambridge, in England, recalls that the U.S. Department of Energy supported the team's research mainly on the grounds that more CO_2 was needed to inject into oil wells for



JUST TAKE OUT THE NITROGEN: In the oxyfuel process, coal is burned in an atmosphere of oxygen and recirculated flue gas. After desulfurization, the flue gases consist mainly of carbon dioxide and water, which are easily separated. In a commercial oxyfuel plant, steam-driven turbines will produce electricity, but the Schwarze Pumpe demonstration plant does *not* have a turbine system. ILLUSTRATION: BRYAN CHRISTIE DESIGN

enhanced recovery. Members of the group and their government sponsors were well aware, even then, that climate change was going to be a growing issue, says Wolsky, but neither they nor the Energy Department promoted the research on that basis.

The Argonne-led group did a series of small-scale demonstrations, controlling for factors such as the coal and gas mixture, temperature, and turbulence, and did computer simulations and analysis. The work attracted attention worldwide, and other experiments followed in Canada, Japan, the Netherlands, and the United Kingdom. It was a time when most work done at U.S. national laboratories was considered public property, and there was not much incentive to secure intellectual property. Wolsky remembers giving oxyfuel talks in Canada, only to be told a year later that Shell Oil had patented the content of his speech.

The initial oxyfuel demonstrations confirmed the technology's promise but also demonstrated the importance of implementing it carefully. For example, when a stoker-fed furnace was used in one demonstration, it was hard to keep air from leaking into the recirculation system; CO_2 concentrations in the flue gas were correspondingly low. Handling pure oxygen is always a dicey business, of course, and so there were concerns about safety. Nevertheless, nothing suggested that oxyfuel firing couldn't work or wouldn't work in a pulverized coal system.

Although Vattenfall itself believes that custom oxyfuel design is the way to go, the retrofit option continues to be assessed by a number of companies, including notably Babcock & Wilcox in Barberton, Ohio. B&W owns a relevant patent portfolio, and its executives have testified to the U.S. Congress on the promise of oxyfiring.

B&W was participating in a plan by SaskPower in Regina, Sask., Canada, to build a 300-MW lignite-burning oxyfuel plant, but that project was put on hold earlier this year and will be reassessed in 2009. Meanwhile, however, B&W has converted a test reactor in Alliance, Ohio, to do oxyfuel combustion. The program of oxyfiring tests began last October and will cost B&W US $14 million to $16 million. It concluded a run with bituminous coal in November and early this year will burn Saskatchewan lignite. B&W is partnering in this demonstration with the French company Air Liquide, a leading provider of liquid oxygen.

The Alliance test reactor, like Schwarze Pumpe, produces 30 MW of thermal energy. But it does not have an oxygen-nitrogen separation facility, and carbon dioxide is not being captured in the tests. B&W is planning a commercial-scale demonstration soon, with both custom-designed new units and retrofit in mind, and it considers itself, with Vattenfall and Alstom, a world leader in oxyfuel.

In terms of retrofit, the most important oxyfuel project on the books is in Australia, where the technology got a government go-ahead in November 2006. (Though Australia, until a new government was elected last fall, had declined to ratify the Kyoto Protocol, it authorized spending 400 million Australian dollars on the development of greenhouse gas–reduction technologies.) CS Energy, of Brisbane, Australia, working with partners in Australia's coal industry and Japanese manu-

RESTORING COAL'S SHEEN

continued from previous page

facturers, wants to backfit a decommissioned 30-MW boiler, Callide A, in Queensland. To that end, CS Energy is doing front-end design work and specifying costs for a project that would involve installing a nitrogen separation plant, flue-gas recycling equipment, a facility to compress and liquefy the carbon dioxide, and the means to transport the CO_2 to a storage site. There are at least a half dozen possible sequestration sites within several hundred kilometers of the plant, both depleted gas fields and saline aquifers, according to Chris Spero, who is in charge of oxyfuel research at CS Energy.

WHAT THE EXPERTS SAY

"Vattenfall's expensive carbon-capture experiment is one of the many costs of the global-warming fad." —Nick Tredennick

"Carbon capture and sequestration is clearly central to the future of coal in a carbon-constrained world. A retrofittable technology would have a big positive impact on our huge inventory of existing coal plants."
—Kurt Yeager, Galvin Electricity Initiative

The retrofitted Callide A plant will burn bituminous coal, not lignite. Spero notes that Australia's soft coals are especially advantageous for oxyfuel retrofit because they are low in sulfur: the flue-gas recirculation system tends to concentrate the sulfur, making its removal more of a problem.

If oxyfuel retrofit could be made to work at low enough costs, the implications would be enormous. In principle, all the existing coal plants in the world could be refitted to run carbon free. But Vattenfall is quite skeptical about that scenario. Particularly because so much energy has to be used to separate oxygen from nitrogen at the front end, the whole process will probably be made economically attractive only when plants are scaled up and customized specially for oxyfiring, says Lars Strömberg, until recently chief engineer and project manager at Schwarze Pumpe and now Vattenfall's head of R&D.

Right now the standard oxygen-nitrogen separation equipment runs on electricity, which has to be obtained from the plant itself, reducing the plant's efficiency of energy conversion by several percentage points. With the development of membrane separation systems, however, the electrical cost of oxygen might come down. And if heat or steam were recovered from an oxyfuel plant to drive air separation, says Strömberg, and the whole plant were customized for oxyfuel at whatever scale turns out to be optimal, then the plant might register an efficiency gain of several points rather than a loss.

Oxyfuel is but one of three basic approaches to carbon capture and storage. In general terms, carbon can be separated from postcombustion flue gases by chemical means, as sulfur and nitrogen oxides are scrubbed, or the bigger part of the job can be done precombustion, either by gasifying the coal or by oxyfiring. In the United States, discussion of carbon sequestration has been dominated by the coal gasification scenario, which generally goes by the acronym IGCC, for integrated gasification, combined cycle.

IGCC involves converting coal into a synthetic gas that can be burned to drive steam turbines, just as if it were natural gas; the waste stream consists mainly of hydrogen, carbon dioxide, and water vapor. Four commercial-scale demonstration plants have been built and are operating, two in the United States and two in Europe. Studies comparing IGCC with oxyfuel and postcombustion carbon capture generally find costs in the same ballpark: the total cost of doing carbon capture and storage using any of the three approaches is likely to be between 25 and 75 percent higher, by comparison with standard pulverized coal. IGCC is generally considered slightly cheaper than oxyfuel, but with large uncertainties.

"There's a perception that IGCC is the only game in town, but our calculations indicate it's *not* the optimal choice, either for hard coal or lignite," says Alstom's John Marion.

IGCC plants are complicated structures that resemble small refineries. They tended to have problems in their early years of operation and by nature require a great deal of maintenance. Their relative economic attractiveness won't really be known until all three carbon-capture approaches have been tested at much larger scales.

And although there are several IGCC plants that are considered adaptable to capture carbon, none have actually done so. So if carbon is captured at Schwarze Pumpe and disposed of permanently in a geologic repository, it will be a first—not just for oxyfuel, but for coal. Although carbon sequestration is not seen as an essential aspect of the project, Vattenfall wants to do a fully integrated demonstration to win public confidence. Stabilizing liquefied carbon dioxide at depths of a kilometer or more has been demonstrated in the North Sea, Canada, and northern Africa.

Vattenfall's Schwarze Pumpe plant builds on a well-developed approach that seems sure to be a part of the solution to the coal-carbon problem. Even if other approaches turn out to be superior for some types of coal, oxyfuel is uniquely suited to lignite, a low-grade and dirty coal found in superabundance in eastern Germany and in some other parts of the world, including Poland and regions of the United States and China. It's likely to be suitable as well for low-sulfur bituminous coals and anthracite.

But even if—contrary to expert expectations—oxyfuel proves to be a technical or economic failure, Vattenfall will still have achieved a moral victory of sorts. This is because Vattenfall will have been the first to initiate and complete a project of significant scale to demonstrate carbon capture and storage with a coal plant. ❑

BRYAN CHRISTIE DESIGN

LOSER: NANOTECHNOLOGY

STILL WAITING FOR NANOTUBE MEMORY CHIP

Nantero's alternative to flash memory has reached its sell-by date *By Philip E. Ross*

Back in October 2001, a Woburn, Mass., start-up called Nantero said it was going to supplant flash memory chips. Business journalists took note: flash memory was then a US $7.8 billion market, and it was growing fast. Even more alluring, Nantero's technology, based on carbon nanotubes, seemed to be the opening salvo in the nanotechnology revolution those journalists had been promising their readers for years.

Nantero called its prospective product the NRAM, the N standing for "Nanotube-based/Nonvolatile." The company's publicity people painted a picture of a computer freed from its last moving part—the hard drive—and thus capable of booting up instantly and surviving hard knocks.

What made the picture compelling was the way the technology seemed to lend itself to mass production. By relying on the properties not of individual tubes but of a mélange of them, Nantero would sidestep the material's biggest bugbear, purity. By laying down the tiny tubes at random, as a kind of fabric, so that patches could reconfigure in response to electronic stimuli, the company would enable data to be encoded mechanically, and therefore permanently. Like costly static random access memory, the NRAM wouldn't lose its contents when the power was switched off. Best of all, the company's fabrication processes would be compatible with standard CMOS lithography, so that chip makers wouldn't face the kind of retooling expenses that dog (and often doom) most new technologies.

These claims, buttressed by functioning prototype chips, got the interest of venture capital firms and garnered the company lots of breathless prose in the technology press. Yes, including us: this reporter, writing in this magazine, had only good things to say about it (see "10 Tech Companies for the Next 10 Years," *IEEE Spectrum*, November 2004).

But that was more than three years ago. And it so happens that two years is the time Nantero has *always* cited in response to questions about when its product would be ready for the market: in 2002 the chips were supposed to be out by 2004; and in 2004, by 2006. Now Greg Schmergel, cofounder and chief executive officer of Nantero, cites the same figure, telling *Spectrum* that "with the right resources, commercial products could be out in a one- to two-year time frame." He says he's talking with major chip makers in the United States, Europe, and Asia and hopes to announce a major deal in a few more months.

Then again, that's what he was saying two years ago, and two years before that.

Skeptics doubt that such speedy development can be achieved. "Every change you make in the electronics industry, as simple as it may look—changing wiring from aluminum to copper, or adding a hafnium insulator—takes 10 years' effort by the entire industry," says Phaedon Avouris, group leader of the Nanoscale Science and Technology Group at IBM Research.

LOSER: NANOTECHNOLOGY

NANOTUBE-BASED NONVOLATILE MEMORY CHIP

GOAL: To store piles of data in a small space, permanently.
WHY IT'S A LOSER: Its time has run out.
PLAYER: Nantero
WHERE: Woburn, Mass.
STAFF: Info not available
BUDGET: US $31 million in venture capital
MORE: http://www.nantero.com

Avouris says the only way forward is to master the science of carbon nanotubes, particularly the problem of achieving the purity that Nantero tries to avoid dealing with by taking its average-of-many-tubes approach. Such averaging throws out almost all of the advantages peculiar to the material, Avouris says, and can be of use only in niche markets. "IBM has never made small trinkets," he sniffs.

Might not little Nantero conceivably do very well off just such a niche market? Maybe, concedes Avouris, but where is the payoff? "They make assertions that they have products, but go look at their Web site," he says. "I see they are offering solutions for others, providing technical support for $190 an hour."

G. Dan Hutcheson, chief executive of VLSI Research, a top semiconductor analysis company in Santa Clara, Calif., is even more pessimistic: "I've been an unbeliever from the beginning," he says. He doubts, specifically, that the NRAM technology can scale well enough to keep up with the ever-shrinking circuit components on standard chips. "The technology itself is very interesting, and it works in the lab, but look how long it took flash to succeed. A company like Nantero can't take such long bets."

Right now, Nantero is relying to a large extent on military R&D funds, says an engineering professor who asked for anonymity. The military wants NRAM chips for their ability to shrug off electromagnetic pulses, such as might be directed against a satellite by an enemy or even an errant solar flare. However, that market is far too small and specialized to serve as a launching pad for commercial electronics, the professor says. He also repeated Hutcheson's contention that Nantero's nanotube patches can't scale down sufficiently to keep up with advances in CMOS technology.

"If you look at the picture of the nanotube fabric in their pictures," he says, "you see it has 200-nanometer holes. Their fabric ribbons can't be smaller than the holes, obviously." For comparison, the smallest features of the CMOS transistors now being manufactured in state-of-the-art facilities measure roughly 45 nm. This professor says that three years ago the company had said it had hopes of finding new chemical processes to align the nanotubes better, and so reduce the pore size, but that it hadn't worked out.

Schmergel rejects the criticism, saying that Nantero has demonstrated a prototype with critical dimensions as small as 22 nm. When it is pointed out that those features were carved with an electron beam, a laborious procedure that could never work in mass fabrication, Schmergel retorts that "even to make the 22-nm prototypes, we needed to solve the porosity problem." Purely chemical fabrication methods capable of scaling down the NRAM will be possible, he adds.

Meanwhile, the years fly by and rival technologies continue to advance, not least among them plain-vanilla flash memory, which is getting better, cheaper, and smaller. That instant-on computer that Nantero sketched out more than six years ago? You can buy one right now for just $400; it's called the iPhone. Cheap flash is the motive force behind One Laptop per Child's XO (often erroneously called the "$100 laptop"), which is being churned out by the tens of millions for the poor countries of the world. It is also what has, in the past year, enabled both Samsung and Dell to introduce powerful instant-on laptop machines.

Sure, flash won't keep getting better forever, but what about the other storage technologies—using magnetism and other tricks—that have far more R&D muscle behind them than the NRAM? How can Nantero keep up?

"It is competing with large companies," notes Dexter Johnson, a nanotech analyst at Cientifica, a consultancy based in London. "Samsung, for instance, has created a $4 billion market for themselves with flash memory. Do you think they are going to idly sit by while some start-up says they are going to make that business obsolete? Not likely; they have their own approach, which they are developing in conjunction with University of Cambridge."

Nantero's patented methods may well find application in completely different products. Just this past September, for instance, HP's inkjet printing people signed an agreement to use Nantero's nanotube techniques to print up inexpensive RFID tags. A few months earlier, Alpha Szenszor, a start-up also based in Woburn, acquired rights to Nantero's technology for use in its medical diagnostic sensors. Such licensing agreements could turn out to be lucrative indeed; a miner who hasn't struck gold can still make a living selling pickaxes to other miners.

But as a mass-market replacement for flash, the NRAM chip looks increasingly like a loser. ❑

WHAT THE EXPERTS SAY

"Now we know where the dumb money goes."
—T.J. Rodgers

"Nantero is impressive and ingenious in its use of characteristics of carbon nanotubes. But the delay in introducing commercial products—there are none yet—may indicate difficulty in achieving manufacturability." —Nick Tredennick

STRONG, SILENT TYPE: Suzuki's prototype fuel-cell bike is clean and quiet but might rely on a nonexistent hydrogen supply. *PHOTO: INTELLIGENT ENERGY*

YOU TELL US

WINNING IDEAS ARE OFTEN DOOMED BY POOR EXECUTION OR BY NOTHING MORE THAN BEING AHEAD OF THEIR TIME. HERE ARE A FEW PRODUCTS THAT COULD GO EITHER WAY. TELL US HOW YOU THINK THEY'LL FARE.

It's the kind of bike you'd expect the hero of a futuristic sci-fi thriller to ride. The sleek, minimalist design of the Suzuki Crosscage is sure to elicit oohs, but it's the bike's performance that will leave mouths agape. Though the hydrogen fuel cell–powered electric motor will likely generate enough torque from a dead stop to leave fossil fuel–powered motorcycles in the dust, the bike emits only water vapor from its exhaust and is whisper quiet. But how many refueling stations in your area sell hydrogen? (We haven't noticed any, either.) It was just this type of conundrum that made labeling the bike and five other items—including a pen that keeps track of what it has written, a head-up display that looks like an ordinary pair of sunglasses, and a computer that's literally on the desktop—winners or losers.

To have your say, go to http://spectrum.ieee.org/jan08/tellus.

FECKLESS INSTRUMENTS? Are a touch-screen computer from Microsoft [left] and a car that morphs into a helicopter [right] more than just expensive novelties?
PHOTOS: LEFT: MICROSOFT; RIGHT: SPARK DESIGN ENGINEERING

FACULTY POSITION IN **MECHATRONIC SYSTEMS ENGINEERING**

School of Engineering Science

Simon Fraser University

The School of Engineering Science at Simon Fraser University is seeking an outstanding candidate at the rank of Assistant Professor for its newly developed program in ***Mechatronic Systems Engineering*** (MSE). As of Fall 2007, the School has been offering graduate as well as a Co-op based undergraduate degree programs in MSE at SFU's newest campus in Surrey. We are interested in a candidate in the general area of Power Electronics with interests in application of embedded and real time systems to motor drives and power control. Specifically, the ideal candidate will also have research interests in a number of the following areas:

DSP-based power electronics,

motor and adjustable speed drives,

development of novel power converters and control strategies,

electric machines and actuators,

electric and hybrid vehicles,

alternative energy and energy storage systems,

biomechanical energy conversion,

energy harvesting, and hybrid energy source systems.

Individuals with an undergraduate and a doctoral degree in Electrical Engineering or closely related area with a demonstrated potential for scholarly and funded research as well as a commitment to undergraduate/graduate teaching are encouraged to apply. Finally, registration or eligibility to register as a Professional Engineer in the Province of British Columbia is a must. This normally requires an undergraduate engineering degree from a reputable university.

The School of Engineering Science has a strong commitment to high quality research and offers an excellent research environment. Initial research support will be provided to the successful applicants for establishing her/his research program. The University has consistently been placed at or near the top of the Maclean Magazine's national ranking. SFU Surrey campus offers brand new state-of-the-art facilities in a central location with outstanding access to the rest of Greater Vancouver via the SkyTrain. The Lower Mainland area of British Columbia is unique in Canada for its mild climate and excellent recreational opportunities.

All qualified candidates are encouraged to apply; however Canadians and permanent residents will be given priority. The University is committed to employment equity and welcomes applications from all qualified women and men, including visible minorities, aboriginal people, and persons with disabilities, gay men and lesbians. Applications will be accepted until the position is filled. Positions are subject to final budgetary approval. Further, under the authority of the University Act personal information that is required by the University for Academic Appointment Competitions will be collected.

For further details see:
http://www.sfu.ca/vpacademic/Faculty_Openings/Collection_Notice.html

To apply, send curriculum vitae, evidence of research productivity (including selected reprints) and the names, addresses, and phone numbers of four referees to:

Dr. Mehrdad Saif, Professor & Director
School of Engineering Science
Simon Fraser University
8888 University Drive Burnaby B.C. V5A 1S6 Canada
email: *saif@ensc.sfu.ca*

Texas A&M

UNIVERSITY AT QATAR

Applications are invited for faculty positions for all ranks: Professor, Associate Professor and Assistant Professor. The positions are available at Texas A&M University at Qatar (TAMUQ) which prepares graduates that satisfy identical requirements and receive Texas A&M University degrees. The TAMUQ campus is situated within a brand new building and is part of Education City, Doha, Qatar, a consortium of educational and research institutions hosted by the Qatar Foundation for Education, Science and Community Development.

TAMUQ began teaching undergraduate students in chemical, electrical, mechanical, and petroleum engineering in the Fall of 2003. As the first students progress through the curriculum, faculty are being added to teach all necessary courses in these majors. The electrical engineering program at TAMUQ offers for the moment only BS degrees but a graduate program in electrical engineering is scheduled to start in the near future. All formal instruction is given in English. More information about TAMUQ can be found at ***http://www.qatar.tamu.edu/***. Specific areas of interest are listed below for guidance but are not intended as a limitation.

Computer Engineering (at any rank): Computer architecture, software engineering, operating systems, distributed computing, compiler techniques, network/processor security, microprocessors and embedded systems, and mobile computing.

Power Systems (at any rank): Generation, distributed generation, transport and distribution of electrical energy, deregulation, forecasting, electrical installations, intelligent buildings (industrial and commercial).

Electronics (at any rank): Analog and Mixed Signal Circuits and Systems, Design, implementation and application of CMOS wireless transceivers; CMOS sensors and circuitry, such as ADC, instrumentation and power amplifiers for a variety of applications, including telemetry.

Applicants must have a Ph.D. or equivalent degree, or completion of all requirements by date of hire. For senior positions, applicants should have a proven record of scholarly contributions and a proven ability to attract research funding. For junior positions, candidates should have demonstrated potential for quality teaching and research.

Starting rank and salary will depend on qualifications and experience. The appointment includes the following benefits according to TAMUQ's policy: air tickets to Doha on appointment; annual home leave allowance for all family members; coverage of the local tuition fees for school-age dependent children; and local transportation allowance. Fringe benefits include health and medical insurance as well as an enrollment in a retirement plan. Initial appointment will normally be on a two-year contract. Re-appointment will be subject to mutual agreement.

Applications, including a full curriculum vitae with list of publications, statement of teaching, statement of research as well as the names, addresses (regular mail and E-mail), fax, and phone numbers of three references to should be sent to:

Dr. Costas N. Georghiades, Department Head
c/o Ms. Debbie Hanson
Department of Electrical and Computer Engineering
Texas A&M University
College Station, TX, 77843-3128.

Texas A&M University at Qatar is an equal opportunity/affirmative action employer and actively seeks the candidacy of women and minorities. The deadline for applications is February 15, 2008 but applicants will be considered until the positions are filled.

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THE GEORGE WASHINGTON UNIVERSITY
WASHINGTON DC

Department of Electrical & Computer Engineering

COMPUTER ENGINEERING FACULTY POSITION

in High-Performance and Reconfigurable Computing

The Department of Electrical and Computer Engineering at The George Washington University invites applications for tenure-track, tenured and contractual non-tenure-accruing faculty positions at all ranks, in the area of Computer Engineering. Two positions will be for tenure-track/tenured faculty, and the third position will be a one-year renewable non-tenure-accruing contractual position at the Assistant/Associate Professor rank, and successful candidates may start as early as Spring 2008. Faculty with research in High-Performance Computing and Reconfigurable Computing are particularly encouraged to apply, however, all areas of Computer Engineering will be considered. Additional information and details on position qualifications and the application procedure are available on **http://www.ece.gwu.edu**. Review of applications will continue until the positions are filled.

THE GEORGE WASHINGTON UNIVERSITY IS AN EQUAL OPPORTUNITY/AFFIRMATIVE ACTION EMPLOYER

Dean.

Melbourne School of Engineering

Established in 1860, the University of Melbourne's School of Engineering is Australia's leading Engineering Faculty (Times Higher Education Supplement discipline ranking - Technology and Engineering). Its vision is to be one of the great engineering schools of the world and the School aims to achieve this vision by ensuring that it has the very best educators and researchers, attracts the very best students and supports them with a world class infrastructure.

Many current School staff are world leaders in their field of expertise, as recognised by nomination to fellowships of prestigious academies and institutions, prizes and medals including the Australian Prize, Centenary Medal, Order of Australia, Victoria Prize and the Prime Minister's Prize for Science.

In appointing a Dean, the School is seeking a high calibre individual with the capabilities and experience to provide strong leadership. The Dean will be an outstanding academic in an engineering discipline with high visibility and wide recognition in their field at an international level. He or she will have a commitment to research and the development of industry and community partnerships. It is expected that the Dean will play a prominent role in developing the profile of the engineering profession in state, national and international arenas. The Dean will also play a prominent role in securing support for the School's development (fundraising) goals.

The successful applicant will be appointed Dean for a period of five years in the first instance. The appointee will also hold a professorial appointment within the University.

Further details relating to selection criteria, appointee profile and The University of Melbourne are contained in the position description.

Remuneration: An attractive remuneration package is negotiable and salary packaging options are available.

The expected commencement date is mid 2009.

For enquiries, contact Professor Peter Scales, Chair, Search Committee – peterjs@unimelb.edu.au

Closing Date: 28 March 2008.

*For position information and to apply online go to **www.jobs.unimelb.edu.au** and search under the job title or job no. 0012201.*

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THE UNIVERSITY OF MELBOURNE

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the data

GREENHOUSE GAS TRENDS

A tale of two perspectives

Last year, critics of the Kyoto Protocol glommed onto statistics showing apparently that the Europeans have been less successful than the United States in curtailing the growth of greenhouse-gas emissions. "Since 2000, emissions of carbon dioxide have been growing more rapidly in Europe, with all its capping and yapping, than in the U.S., where there has been minimal government intervention so far," wrote the *The Wall Street Journal*'s Kyle Wingfield, in a typical comment.

Kyoto commits industrial countries to collectively cut their emissions roughly 5 percent from the 1990 level by 2008–2012. The United States is the one industrial country that has declined to ratify the protocol.

A look at statistics compiled by the United Nations Framework Convention on Climate Change (UNFCCC), in Bonn, provides grist for both mills in the Kyoto debate. The United Nations' statistics for 2000 to 2004 did indeed show the United States outperforming the 15 countries that were members of the European Union when the protocol was adopted in 1997. And last month, when the United Nations released its figures for 2005, the aggregate emissions of 25 current EU members (not counting Cyprus and Malta) were 1.8 percent higher than in 1990, while U.S. emissions were up just 1.6 percent.

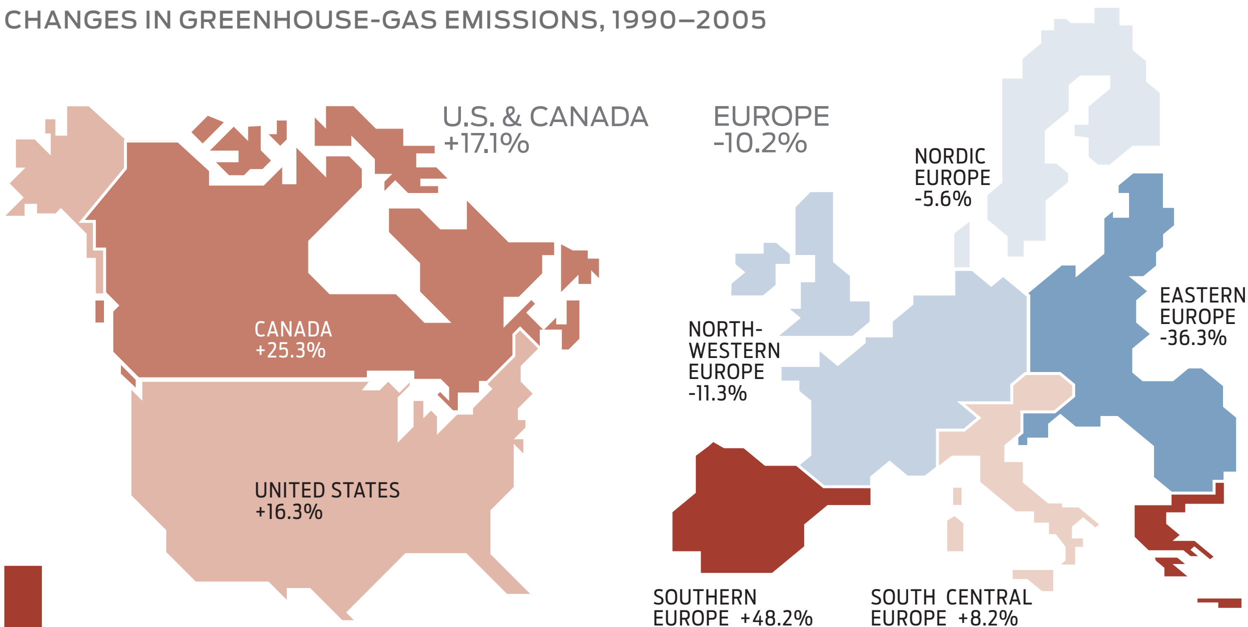
Clearly there's no one-to-one relationship between Kyoto membership and success in meeting its targets. But it would be wrong to conclude that there's no relationship at all, or that the overall U.S. performance is better than Europe's.

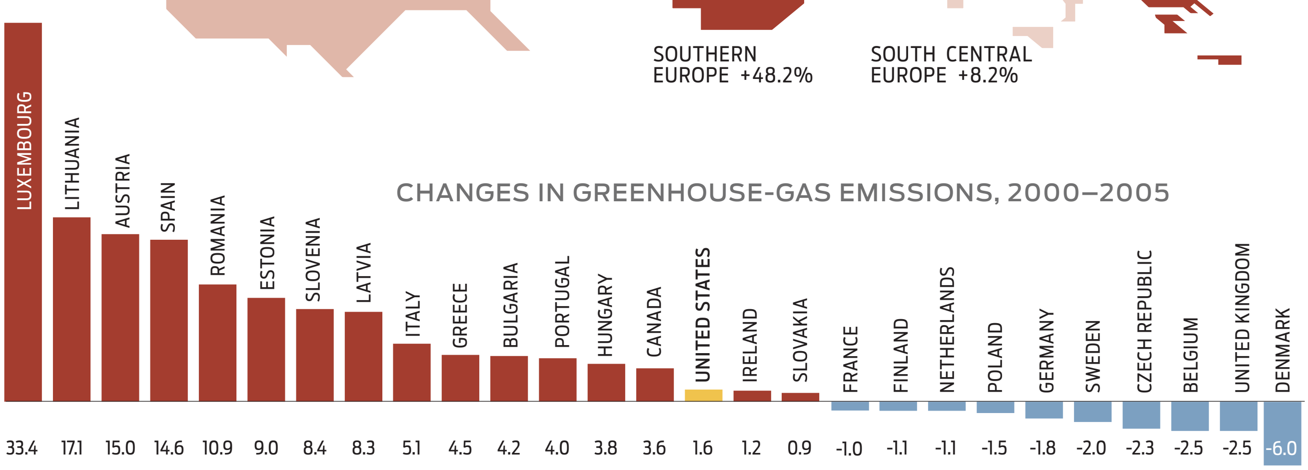
Considered in the context of the Kyoto compliance period starting in 1990 [map] and taking the current membership of the EU into account, Europe has cut its emissions 10.2 percent, while U.S. emissions have increased 16.3 percent. The individual countries that have been most vocal in support of Kyoto have especially reduced their emissions [bar chart], while emissions have been rising sharply among many of the newer EU members in southern and eastern Europe. —WILLIAM SWEET

WHEN EUROPEAN and U.S. greenhouse-gas emissions are compared for the period from 1990 to 2005 [map], emissions of 25 European Union members (not counting Cyprus and Malta) are down 10.2 percent, while U.S. emissions are up 16.3 percent. But in the more recent period, 2000 to 2005 [bar chart], the emissions of many individual European countries have gone up far more than U.S. emissions have.

SOURCE: UNFCCC
RESEARCH: MORGEN PECK
CHARTS: BRYAN CHRISTIE DESIGN

CHANGES IN GREENHOUSE-GAS EMISSIONS, 1990–2005



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