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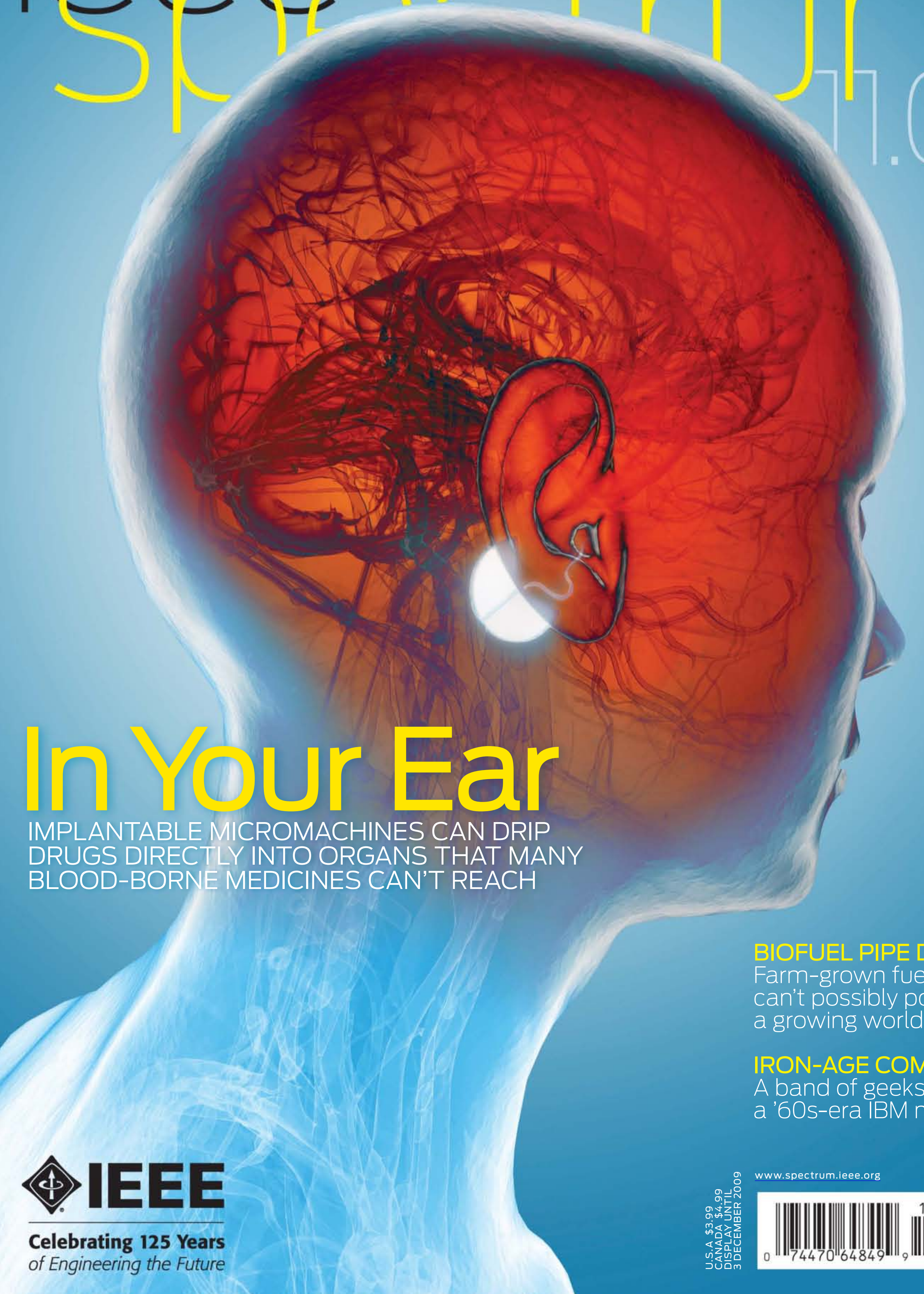

In Your Ear

IMPLANTABLE MICROMACHINES CAN DRIP DRUGS DIRECTLY INTO ORGANS THAT MANY BLOOD-BORNE MEDICINES CAN'T REACH

BIOFUEL PIPE DREAM

Farm-grown fuels can't possibly power a growing world

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A band of geeks rehabs a '60s-era IBM mainframe

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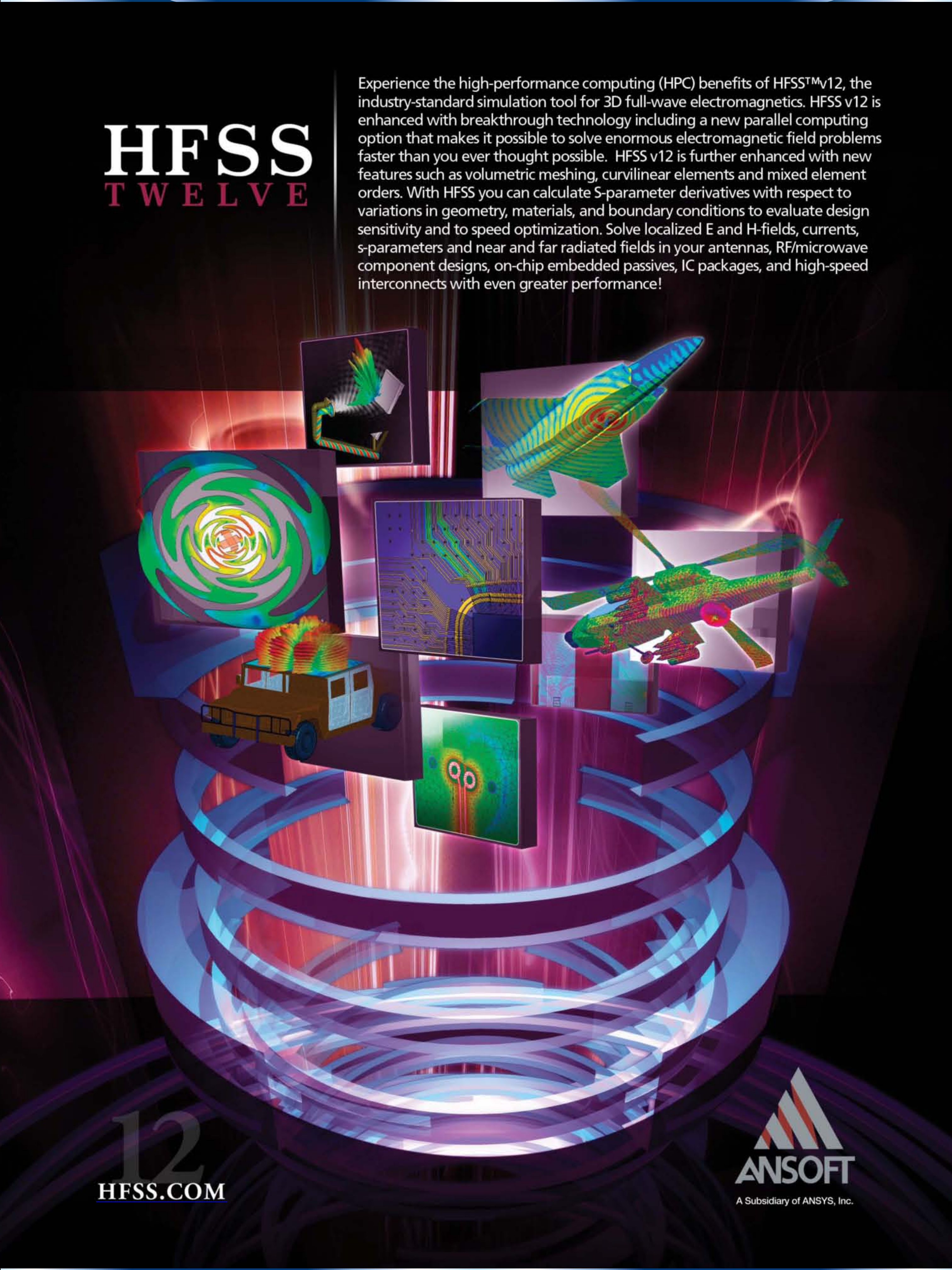
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AIRY VISION: The makers of this prototype car believe that batteries will remain too expensive to power green vehicles. Their answer is a pneumatic engine.

COVER: BRYAN CHRISTIE DESIGN

THIS PAGE: VINCENT LIGNIER

UPDATE

OPINION

DEPARTMENTS

volume 46 number 11 international

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PHOTO: ATR INTELLIGENT ROBOTICS AND COMMUNICATION LABORATORIES

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ROBOTS FOR REAL

In a series of audio slide shows, scientists and engineers show how they are bringing robots into our daily lives. We talk with Swiss researchers teaching robots to walk, visit a Silicon Valley start-up developing open-source robots, and hear how one Japanese roboticist [right] is using androids to study human-machine interaction. Go to http://spectrum.ieee.org/special-reports/robots to see how these and other robotics projects will transform our lives—for real.

ONLINE FEATURE

CAPTURING SOUND WITH SMOKE AND LASERS: Audio engineer David Schwartz was out to dinner with his wife when he noticed their voices disturbing the smoke from a candle on the table. Schwartz and his son used this as inspiration in developing a new type of microphone with no mechanical parts. Instead of detecting sound waves with a vibrating diaphragm, their device uses lasers to measure deformation in a stream of smoke. Watch the video to see a demonstration of the new microphone.

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HOW GOLD MEMBERSHIP HELPS YOUR CAREER: Recent news reports say some engineering grads are having difficulty finding jobs in these tough economic times. That's where the IEEE Graduates of the Last Decade (GOLD) group comes in. Find out how GOLD has helped its members get their careers started.

SECURITY GROUP TO COMBAT MALWARE: The IEEE Standards Association's Industry Connections program has brought together some of the biggest names in security to form a group and pool their resources to fight the increasing barrage of malicious software.

TWO TV DEVELOPMENTS EARN MILESTONES: Pioneering developments in television and the first reception of a transpacific TV signal via satellite are being honored this month with IEEE Milestones in Electrical Engineering and Computing.

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back story

A High-Pressure Assignment

In his travels as a contributing editor for *IEEE Spectrum*, Peter Fairley has had some unique experiences: hanging out with electrical workers in the Libyan desert, interviewing residents of remote Bolivian villages about their solar-fed LED lamps, and hearing cyclists in Beijing gripe about their government's rejection of two-wheeled transport.

So when we called last March and asked him to drive a tiny prototype car [above] powered by compressed air and steered with a joystick, the request didn't faze him a bit. "A high-pressure job, but someone's gotta do it," he responded. Did we mention that the company behind this minicar, Motor Development International (MDI), is putting these diminutive vehicles together just outside Nice, in France?

Fairley found the prototype enticing: It's attractively styled, surprisingly quiet, feels peppy, and is easy to operate. The testing area next to the company's plant was small, though, so Fairley wasn't able to explore the vehicle's full performance envelope. He didn't even push the car past 30 kilometers per hour (19 miles per hour), and he took the curves gently, even though the car can turn on a dime. "It felt a little tippy," explains Fairley.

Though he took it easy on the test vehicle, he is much harder on the company in his article "Driving on Air," in this issue. And he's not alone in his skepticism. Unlike some of MDI's European critics, however, Fairley kept an open mind as he gathered information and conducted interviews at the company's research and fabrication facility in France's coastal playground. "Despite Nice's many distractions, the engineers at MDI are working hard in pursuit of an economical, green-transport solution. Their product deserves the close look we've tried to give it," Fairley says. ❑

CITING ARTICLES IN IEEE SPECTRUM

IEEE Spectrum publishes two editions. In the international edition, the abbreviation INT appears at the foot of each page. The North American edition is identified with the letters NA. Both have the same editorial content, but because of differences in advertising, page numbers may differ. In citations, you should include the issue designation. For example, the first Update page is in *IEEE Spectrum,* Vol. 46, no. 11 (INT), November 2009, p. 11, or in *IEEE Spectrum*, Vol. 46, no. 11 (NA), November 2009, p. 13.

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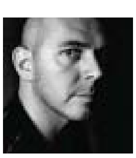
contributors

DEEPAK DIVAN, an IEEE Fellow and president of the IEEE Power Electronics Society, is a professor at Georgia Tech, where he works with graduate student **FRANK KREIKEBAUM.** After 30 years in energy-efficiency engineering, Divan has heard some exotic schemes for going green, including an underground nuclear park and superconducting pipes that pump liquid hydrogen. The model he and Kreikebaum describe in "Organic (But Not Green)" [p. 46] isn't nearly that wild, but the results did raise eyebrows. Kreikebaum, who holds degrees in electrical engineering and philosophy, is interested in "the broader questions that arise from societies and systems" and hopes the model will spur public debate.

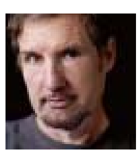
JEFFREY T. BORENSTEIN's first experience with the Massachusetts Eye and Ear Infirmary was as a patient in the hearing department. Three years later he started collaborating with MEEI on microfluidics-based drug delivery for the inner ear, a project he describes in "Medicine by Micromachine" [p. 34]. A solid-state physicist at the Charles Stark Draper Laboratory, in Cambridge, Mass., Borenstein says he "always had a fascination with medicine and wanted to find opportunities to get involved in human health."



VINCENT LIGNIER photographed the green-car contender AirPod in Nice, France, for "Driving on Air" [p. 28]. His biggest challenge in capturing the futuristic pod was trying to even out the car's reflection while shooting. "It's like an egg," he says. "If there's no reflection in one part, it's reflecting somewhere else." Lignier's work has been featured in such publications as *Rolling Stone*, *Vibe*, *Forbes*, and France's *Libération*.

ROBERT W. LUCKY reflects this month on the changing nature of engineering challenges [p. 21]. In the 20th century, engineers used to invent things; now they develop systems. Lucky, an IEEE Fellow, holds 11 patents and worked for many years at Bell Labs. Before retiring in 2002, he was vice president for applied research at Telcordia Technologies, in Piscataway, N.J.

PRACHI PATEL, an *IEEE Spectrum* contributing editor, reports that things are looking up for engineers in the aerospace job market [p. 20]. Patel, who holds a master's in electrical engineering from Princeton, has written for *Discover* and the Web sites of *Scientific American* and *Technology Review*. You can also hear her on Spectrum Radio and Public Radio International's "Living on Earth."



MARK RICHARDS was impressed by the "priesthood" of IBM engineers who rebuilt a 1960s-era IBM 1401 from memory, a group he photographed for "Computer Reborn" [p. 40]. He started photographing computers out of "desperation and insecurity" for his book *Core Memory: A Visual Survey of Vintage Computers*. Bringing computer parts to life takes constant study, says Richards, who served as a naval intelligence photo analyst during the Vietnam War. "I stare a lot," he says. "That steady scrutiny allowed him to see the "anthropomorphic qualities" of computer wires, which reminded him of Leonardo da Vinci's autopsy drawings.

CLOCKWISE FROM TOP RIGHT: STEPHEN LACKO; JOEL PREDD; MARK RICHARDS; JEROME DE PERLINGHI; CHARLES STARK DRAPER LABORATORY

spectral lines

ARTISTS AND ENGINEERS joined forces at WQXR, including pianist Jascha Zayde [below] and soundman Robert Cobaugh [right].

THE NEW YORK TIMES/REDUX

It's the Stupidity, Stupid

Last month, the storied classical music radio station WQXR, in New York City, ceased operation as a powerful commercial station and become a public radio station with a considerably weaker signal. Fatuousness is on the march, and this is an important milestone.

WQXR was the first—and the last—commercial classical music station in the New York City area. It has been sold as part of a three-way, US $45 million deal that sent WQXR's coveted slot on the FM dial and its powerful transmitter to a Spanish-language station and its venerable call letters to the public radio stations of WNYC. On 8 October, 6000 glorious watts began pumping cheesy sound effects, shouting, and frenetic salsa music into the ether at 96.3 FM in the New York City area, while Mozart, Beethoven, and Stravinsky now make do with 600 W at 105.9 FM.

In news articles and press releases, *The New York Times*, which sold the station, and WNYC emphasized that the deal was a win for classical radio. But it's hard not to look at the facts without concluding that a unique piece of technology history is being lost and that classical music has passed a critical juncture in its decades-long decline as a viable entertainment medium.

Every new form of mass media—motion pictures, radio, television, the Internet—has been initially cheered by dreamers who saw in the new technological medium opportunities to bring humankind's great achievements to the masses. With precious few exceptions, those hopes have always been quickly dashed.

For 73 years, WQXR was one of those exceptions. It was founded in 1936 by Elliott Sanger and John V.L. Hogan, an electrical engineer and music lover who had been a protégé of two of the greatest engineers of that era: Reginald A. Fessenden and Lee De Forest. In the 1930s, Hogan, who had earlier made his name by inventing a radio set that could be tuned with a single dial, was working on a form of mechanical television and operating an experimental radio station over a garage in Long Island City, in Queens. During dinner in Brooklyn in the fall of 1935, Hogan and Sanger became seized with the notion of turning Hogan's little 250-W station into a more powerful commercial operation unlike any other then on the air. Commercial radio in those days, as now, was a mix of mostly lowbrow humor and forgettable music.

Hogan and Sanger wanted to play good music and turn away tasteless advertising. People thought they were crazy. A few years later, *Harper's* magazine quoted Hogan as saying, "We assume the radio audience to be an intelligent and cultured person"—to which the article's author, Henry F. Pringle, added, "It is an assumption which would qualify Mr. Hogan for a lunatic asylum in the minds of nearly all other radio company officials."

It took seven years to turn a profit. With its emphasis on the listening experience, and with the tech-savvy Hogan as its initial majority owner (*The New York Times* bought the station in 1944), WQXR soon became a hotbed not only of culture but also of technological innovation.

On 18 July 1939, the WQXR studio was the source of the first regularly scheduled broadcast in frequency modulation (FM), arranged by radio pioneer Edwin H. Armstrong. Some years later, when the station was simulcasting on both AM and FM, it encouraged listeners to tune a radio to each of the two broadcasts and then position each of the radios on opposite sides of a room. It was a remarkable, pathbreaking attempt at what would later be called stereo broadcasting.

In a book he wrote in the early 1970s, Sanger casually mentions that classical music made up 20 percent of record sales in the mid-1960s and bemoans that the percentage had slipped since then. He didn't live long enough to see the real plunge: In the United States, classical music now accounts for less than 1 percent of record sales, according to the International Federation of the Phonographic Industry.

Today there are alternatives for the classical-music lover, including continuous programming delivered by satellite and cable. There is also a panoply of Internet-based options, such as Pandora, a personalized radio service, and the streaming Internet simulcasts that virtually every radio station now offers. But none of them can substitute for a well-run classical-music station with knowledgeable hosts and robust ties to the local scene.

So I'll hope for the best. WNYC has pledged to keep WQXR's all-music format, augmenting it with programming of its own. I'll keep listening. What other choice do I have? —Glenn Zorpette

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forum

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SO YOU WANT TO BE A ROCK STAR?

I ENJOYED THE article on the *Rock Band* video game and all the engineering that went into it ["The Making of *The Beatles: Rock Band*," September]. I hope the story is picked up by the popular science sites as an example of the complexity required to make things easy and intuitive to operate. I am also hoping the game's development team can extend the structure to help people learn to actually play a real instrument. After all, without original music, there would be no foundation for the karaoke-air-guitar experience.

H. Ward Silver
IEEE Member
Seattle, Wash.

ON THE AIR

MITCHELL LAZARUS'S suggestions on avoiding trouble with the Federal Communications Commission when launching a new technology ["Radio's Regulatory Roadblocks," September] are very well taken. However, by suggesting that only federal lethargy is responsible for stifling innovation, he is ignoring the role of international agreements and the World Radiocommunications Conference in U.S. regulation and licensing, especially regarding satellite systems. Also, the suggestion that amateur radio opposition to broadband over power lines (BPL) was based on fear ignores the doubts about the veracity of BPL interference calculations and the fact that interference did indeed occur after deployment. Fear is not always baseless, and "amateur" does not necessarily mean technically uneducated.

Dennis R. Rossbach
IEEE Member
Corrales, N.M.

DIVERSIFY, DIVERSIFY

GEORGE F. STEEG'S letter ["Energy by the Numbers," Forum, September] missed some important points about wind and solar energy. First, it's immaterial that a single nuclear power plant might have 1000 times the generating capacity of a single windmill. In fact, that's an advantage to windmills. Windmills can be installed incrementally and in a distributed fashion. Second, solar can be installed on top of existing urban infrastructure. Urban solar reduces peak transmission demand when transmission capacity is at its lowest. Just as solar has a hard time producing electricity at night, nuclear has a hard time ramping up electricity during the day.

For the foreseeable future, we'll have to put up with nuclear, and we'll need much better carbon and mercury capture on coal plants. But we also need to continue to push wind and solar and pray that the promise of these technologies pans out.

Chuck Simmons
Redwood City, Calif.

COME BLOW YOUR PHONE

HAVING READ the description of my work in "The iPhone's Music Man" [Careers, September], I would like to say that while I am responsible for designing Smule's iPhone Ocarina, I am not the first to use a microphone to make music, and not even the first to make music on mobile phones. The process of tracking a microphone signal is well known and has been used in computer music. For example, Matt Hoffman created an instrument for the Princeton Laptop Orchestra in 2006 called "Breathalyzer?" that lets players blow into the onboard microphone to dynamically control sound. Ananya Misra, Georg Essl, and Michael Rohs published a research paper in 2008 titled "Microphone as Sensor in Mobile Phone Performance" that describes various strategies for music making on mobile phones—including one that uses a blowing gesture and another that exploits a camera for tone-hole control.

Ge Wang
Stanford, Calif.

MAKING WAVES

FOR THE record, in "Data Monster" [September], the cavity magnetron as used in World War II radar and microwave ovens wasn't invented in the 1920s at General Electric. It was invented in Germany by Hans Hollmann in 1935 but developed by John Randall and Harry Boot, then at the University of Birmingham, in England, in 1940. Their device was about 100 times as powerful as Hollmann's.

Nick Weston
IEEE Member
Peebles, Scotland

Michael N. Geselowitz, Staff Director, IEEE History Center, Rutgers University, responds: The magnetron evolved over time. Albert Hull invented the first magnetron, a two-pole device, at GE in 1920, which he and others subsequently developed throughout the 1920s. Hollmann invented the first cavity magnetron in 1935. Randall and Boot developed the vastly more powerful and reliable cavity magnetron used in World War II. As with all technological inventions, the story of the magnetron involves many "inventors" and is convoluted but fascinating.

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update

Plastic Solar Cells Roll Into Unlit Villages

Printed roll-to-roll organic PVs may not be the most powerful, but they're cheap

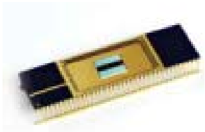
PLASTIC POWER: Plastic solar cells integrated with batteries and LEDs could replace kerosene lamps.
PHOTO: FREDERIK KREBS

By day, the electronic devices that Frederik Krebs rolls off his printing presses could be mistaken for old plastic overhead-projector transparencies. Nightfall reveals their ingenious purpose: Snap the metal fasteners at the corners together and the sheets glow with reading-quality light. Krebs's sheets may prove to be much more than a curiosity, for the senior scientist at Denmark's Risø National Laboratory for Sustainable Energy has found a cheap way to integrate LEDs, photovoltaic (PV) cells, and ultrathin lithium batteries into a potentially life-saving lamp. He hopes to see them on sale next year, providing an affordable alternative to kerosene lighting for the more than 1.5 billion people in developing countries who lack access to electricity.

Success would also mark an important first step to commercialization for the lamp's cheap-to-produce yet anemically inefficient organic photovoltaic technology. Most organic PVs are composed of conducting polymers and carbon nanostructures, which in the right combinations mimic the *p-n* junction of silicon and other inorganic photovoltaics. Efficiency is significantly lower, however, because polymers are poor charge conductors. "This is the lousiest of the solar technologies available," admits Krebs.

That's not for want of trying. Andrew W. Hannah, CEO of organic electronics materials developer Plextronics, says materials advances are bringing polymer PVs within reach of some niche applications. He says testing at the U.S. Department

update



news brief

Phase Change
Samsung says it has started the first commercial production of phase-change memory chips. Known as PRAM, this nonvolatile memory technology holds bits according to the conductive phase of a special material, which melts to change phase. The company claims that PRAM could extend a cellphone's battery life by more than 20 percent. Samsung's main competitor, Numonyx, says it will start shipping samples of its own PRAM late this year.
PHOTO: SAMSUNG

of Energy's National Renewable Energy Laboratory, in Golden, Colo., is confirming that polymer PV materials can survive outdoors for years if they're effectively encapsulated from air and water. Efficiency is rising too. Hannah says that Plextronics, based in Pittsburgh, will release a new set of polymer "inks" in the first quarter of 2010 capable of delivering 6 to 6.5 percent efficiency in small cells—a 1 percentage point improvement over Plextronics's prior best. These specs should, Hannah predicts, enable product development firms to begin using polymer PV materials in portable, low-energy applications such as battery charging and distributed sensing.

Large modules of organic photovoltaics like Krebs's, however, capture just 1 to 2 percent of the photon energy that hits them. And yet, Krebs says, even that measly return adds value in the price-sensitive context of rural lighting.

Access to sustainable lighting remains a tough nut for engineers to crack [see "Lighting Up the Andes," *IEEE Spectrum*, December 2004]. Off-grid villagers in Africa, Asia, and Latin America still rely on kerosene lamps and candles, with the average household spending US $40 to $80 annually for their dim, soot-belching light, according to Germany's development agency, the Deutsche Gesellschaft für Technische Zusammenarbeit, or GTZ. A 2009 assessment by GTZ found that the cheapest solar-LED lighting solutions marketed today cost as much as a full year's worth of kerosene.

FIELD TEST: Students in Zambia test early polymer photovoltaic-powered lights developed in Denmark. PHOTO: FREDERIK KREBS

Krebs's lamps should crash through that cost barrier. He prints their polymer solar cells and circuitry onto rolls of 25-micrometer-thick flexible plastic film by the hundreds of square meters, using standard screen and slot-die presses. Next, a circuit of copper tape is printed onto the solar cells, and the components—surface-mounted LEDs, flat batteries, and a diode—are mounted using silver epoxy. The whole thing is then encapsulated in a second sheet of film.

The total cost of the prototypes produced in Krebs's Copenhagen-area lab is €18 ($27) per lamp. Krebs says that commercial partner Mekoprint Electronics, in Støvring, aims to produce an improved version this fall for €7. He estimates that cheaper labor in China could cut Mekoprint's cost in half.

Mekoprint's version will benefit from the field testing of 196 prototypes in Zambia this summer. Danish business school students handed out the lamps to children attending the summer school the Danes run at a coffee farm outside of Lusaka, a grid-connected area plagued by daily blackouts. Excessive flexing of the 1-millimeter-thick sheets caused some to delaminate, a problem that Krebs and Mekoprint hope to fix by repositioning the solar cells within the plastic sheet. And the quality of the light was found to degrade after 10 to 20 minutes, inspiring the addition of circuitry to feed power to the LEDs at a constant current. Testing of a further 1000 to 2000 next-gen lamps in Mali and Malawi is anticipated after the fall rainy season.

Krebs expects the lamps to operate for at least a year, which he deems reasonable for a lamp that will cost less than one-quarter of the buyers' present annual lighting budget. "This is an affordable lamp, and it's better than no lamp," he says.

—PETER FAIRLEY

400 The number of DVDs that could have been sent from Paris to Chicago in one second on a single fiber during a recent demonstration. In the test, scientists at Alcatel-Lucent's Bell Labs pushed their system past 100 petabits per second, per kilometer.

New Director for U.S. Energy Department's Mad Science Wing

Energy efficiency will likely be the focus

On 18 September, President Barack Obama chose Arunava Majumdar as the director of the Advanced Research Projects Agency–Energy (ARPA-E), the U.S. Department of Energy's new research incubator. Majumdar is currently director of Lawrence Berkeley National Laboratory's Environmental Energy Technologies Division and a professor at the University of California, Berkeley. His appointment provides clues to the future direction of an agency that many hope will drive innovation in energy technology and one that has been, until now, famously rudderless.

ARPA-E's goal is to create game-changing energy technologies from high-risk research gambles. The agency is fashioned after the Defense Advanced Research Project Agency, a model that has already been copied by other U.S. government arms to create IARPA (intelligence) and HSARPA (Homeland Security). The director reports only to the energy secretary and is supported by a lean core staff (capped at 120) that's directly responsible for all funding. Its proponents, therefore, hope ARPA-E will be able to award grants quickly and free of bureaucratic delays.

The agency was created by law in 2007 but languished for two years as funding and interest lagged. But then incoming President Obama tapped Nobel Prize–winning physicist Steven Chu to lead DOE. Chu, who coauthored the 2005 report that kindled ARPA-E's creation, was responsible for selecting its director. He took his time with it: "They were really careful about making sure the right person was at the helm," says Chris King, a staffer in the House Committee on Science and Technology.

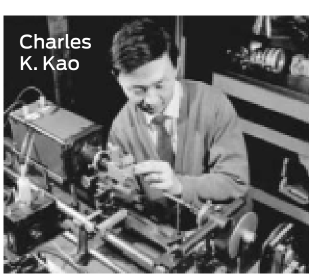
Majumdar will not start his job until he is confirmed by the Senate, but some experts say his first day can't come soon enough. The agency has already taken some heat for starting without a leader. Two months after the administration funded the fledgling agency with US $415 million, it solicited research proposals, and 3500 poured in. But the agency had no director and only a handful of employees, so volunteers—technical reviewers recruited from government, industry, national labs, and universities—stepped in to choose 200 proposals to fund.

Their decisions drew much ire from rejected researchers, but not everyone agrees that the process was flawed. "ARPA-E is already proving that it is not mired in bureaucracy and bogged down in process," King says.

In the same way, Majumdar's nomination bodes well for the agency, says King. "He knows DOE well enough to know what ARPA-E needs [for it] to be different from DOE."

IEEE Fellow Meyya Meyyappan of NASA Ames Research Center, in California, says that Majumdar is interested in energy efficiency research and alternative energy storage approaches. The Ames senior scientist adds that the director-designate wants to make the United States energy self-sufficient. Meyyappan, who collaborated with Majumdar in 2006, calls him a "brilliant" mechanical engineer and "a natural choice to head ARPA-E." —Sally Adee

Nobel Prizes for Three IEEE Fellows



Charles K. Kao

Willard S. Boyle [left] and George E. Smith

Digital cameras generate much of the data on our optical-fiber telecommunications networks. The 2009 Nobel Prize in Physics recognizes both inventions. The prize went to Willard S. Boyle and George E. Smith for the invention of the CCD imager and also to the grandfather of optical-fiber telecommunications, Charles K. Kao. IEEE Spectrum Online is exploring the history of the invention of the CCD: See http://spectrum.ieee.org/consumer-electronics/gadgets/ccd-camera-chip-pioneers-share-nobel.

PHOTOS: LEFT, NORTEL; RIGHT, ALCATEL-LUCENT/BELL LABS

1 MILLION The number of electric vehicles Germany plans to have on the road in 2020.

Chip Design Thwarts Sneak Attack on Data

Cache architecture harnesses the power of randomization

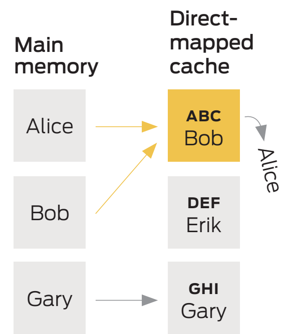
Data encrypted on your computer should be safe, as long as you're the only one with the key to the encryption. But one variant of newer—and sneakier—attacks can deduce the key by striking a vulnerable spot: the CPU's on-chip memory, called the cache. Software-based attempts to bolster cache security have bad side effects, however, which can severely degrade the computer's performance. Now researchers have developed a new kind of cache architecture that neutralizes these attacks. They found that combining the best qualities of the two main types of cache had amazing results: a secure cache that also handles data faster and consumes less power.

The new technology, called Newcache, developed at Princeton University by electrical engineering professor Ruby Lee and her graduate student, Zhenghong Wang, foils these so-called cache side-channel attacks by randomizing where data is stored in the cache.

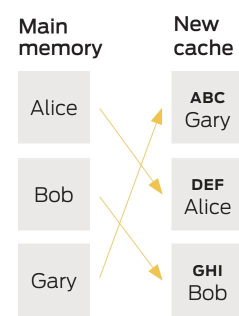
A CPU's cache copies data that the processor uses frequently from a computer's main memory and temporarily stores it. This reduces greatly the amount of time needed to retrieve data, so it speeds up processing.

A cache organizes the incoming data logically to make it easy to find. "If you throw data just anywhere into your cache," says IEEE Fellow Mark Hill, a computer science professor at the University of Wisconsin–Madison, "when you need to find it, you have to look for it everywhere." So caches use an addressing system that can be conceptually compared to a rudimentary address book. "Your friend Alice will be stored in the ABC section or nowhere," he explains. The good news: Finding Alice is easy. The bad news: Because the cache is comparatively small, there is room for only one entry in the ABC section. Adding your friend Bob would kick Alice out of the cache. This is called a conflict miss, a term Hill coined in his 1987 Ph.D. thesis.

Here's how a side-channel attack works to exploit that organization. An attacker fills the address book with his own entries, including, say, Bob. When you add a new ABC entry, Alice for instance, Bob is booted out. The attacker doesn't know that the new entry is Alice, because of the encryption. But he can deduce that the new entry belongs in the ABC group, because it was Bob that was booted. By observing millions of conflict misses and using some algorithmic magic, an attacker can figure out the key that encrypts your data.



OLD WAY: Data from main memory is rigidly organized in the cache. When one section of the cache is full, new data sent to it kicks out the old data.



SAFE WAY: Data from main memory is randomly organized in the cache, so there is less of a chance that incoming data will need to kick out old data.

The way Lee's new hardware design solves this issue is subtle, Hill says. From the outside, the new cache system appears to map entries as a standard cache would—Alice in ABC, Doug in DEF, and so forth. But what it's really doing is putting new data into available slots in any part of the cache. That means Alice, Bob, and Carol can be stored simultaneously, because now Bob might populate the MNO slot and Alice the STU slot. Conflict misses will still happen when the cache is full, but they no longer carry the information a hacker could use to crack the code.

Before Lee's work, no cache architectures had been designed specifically to fend off attacks. The only previous hardware security solutions revolved around what Lee calls "unacceptable brute-force solutions" that slowed computers down. Because it reduces the number of conflict misses, Newcache improves performance even for applications that don't need security. It also improves power consumption and fault tolerance and keeps parts of the chip cooler, she says. "The key point is that Newcache improves performance as it improves security," Lee says.

Lee, who is also an IEEE Fellow, says several processor firms have already expressed interest in the technology. But its adoption will depend on more than the fact that it works better and keeps data more secure, says David Kanter, a consultant at Real World Technologies. "That means evaluating the overall costs and benefits of a secure cache, in terms of design complexity, performance, verification, and validation—not just whether it makes your cache more secure."

—Sally Adee


Imagination
Ideas
Innovation
Creating engineers for a borderless planet
Professional Master's Program
Enhance your B.S. degree in ECE and enhance your value to industry.
• Earn a Master's in Electrical and Computer Engineering in 12-18 months.
• Complete an optional project as part of the degree
• Fellowships available for qualified applicants
Ph.D. Program
Create original research in a program ranked in the Top 5 in the U.S.
• Enter the program with either a B.S. or an M.S.
• Study with highly respected faculty with entrepreneurial experience
• Be part of a collaborative team at a university known for its interdisciplinary research.
• Dean's Fellowships available for qualified applicants
Carnegie Mellon
Electrical & Computer ENGINEERING
Applications accepted at:
www.ece.cmu.edu
Women and Minorities are encouraged to apply

gifts

THE HUNDRED-GRAND GRAND

The Yamaha AvantGrand digital piano packs a concert piano experience into an upright's size and price

Yamaha AvantGrand
http://www.avant-grand.com
http://www.yamaha.com
N3 list price: US $19 999;
N2 list price: $14 999

THERE ARE home pianos and there are concert grand pianos, and unless you've resided in Graceland or Neverland, the two have always been quite different things. First, there's the size—a concert grand piano is at least 2.5 meters (8 feet) long. Then there's the cost—US $120 000 and up. But surely in today's digital world, we should be able to simulate the concert experience in our own living rooms, right?

That task has turned out to be surprisingly hard. But Yamaha, the world's largest manufacturer of musical instruments, may have finally done it with its AvantGrand digital piano. Using its 2.7-meter (9-foot) CFIIIS concert grand piano as its inspiration, Yamaha has spent the past 15 years developing a digital piano for the rest of us.

GRAND ILLUSION: Yamaha's AvantGrand re-creates a concert grand piano's sound digitally.
PHOTO: ERICO GUIZZO

I found the response and the feel quite expressive. The piano mimics an acoustic instrument, with transducers inside reverberating at the touch of your hands and feet, and superb keyboard action remarkably similar to that of Yamaha's large grand pianos. Yamaha has also sampled all 88 notes from four locations within the CFIIIS; the AvantGrand replays them through four speakers located in corresponding positions to emulate the sound of notes bouncing off a grand piano's lid.

Does it sound like a hundred grand? No. The technology needed to replicate an exquisite, handcrafted instrument like the CFIIIS doesn't exist and possibly never will. However, the AvantGrand sounds and plays better than many acoustic pianos in the $15 000 to $20 000 range while requiring little space and no tuning. Its sound tends to be a bit bright, producing unflattering overtones during complex musical passages. Customizable equalization controls would remedy this.

Like most keyboards, the AvantGrand can produce other instrument sounds, but the acoustic piano is clearly its forte. It offers many of the other benefits of a digital keyboard, including a headphone port for late-night recording sessions. Speaking of which, there's a built-in recorder that produces files that can be downloaded to a USB drive.

The AvantGrand comes in two models. The "upright" N2 lists at $14 999. The flagship N3 model lists at $19 999 but seems to offer little more than a "grand piano" body design—in my brief showroom session, the two sounded and felt quite similar. I'd be happy to make space for either in my home.

—MARK MONTGOMERY

A NEW SPIN ON AN OLD TOY

The humble yo-yo gets a high-tech makeover

THE YO-YO, like the Frisbee before it, has gone pro.

It's no longer just a US $2 piece of circular plastic that unspools down a string and spools back up. A top-of-the-line yo-yo these days is a precision-engineered device with a two- or three-figure price tag. Just ask Ernest Kaiser, a.k.a. "General-Yo," an aerospace engineer working in Riverside, Calif., for a "medium-sized company that supplies big companies," as he puts it.

Hat Trick US $100; General-Yo;
http://generalyo.com
[photo unavailable; 5-Star is shown]

Last year, when out shopping for a new computer mouse, Kaiser ran across a bin of Duncan plastic yo-yos and picked one up on a whim. He hadn't played with one since he was a kid. (The yo-yo term of art, Kaiser soon learned, is *throwing* rather than *playing*.) Some number of throws and Google searches later, Kaiser discovered an entire Internet yo-yo subculture

New Breed $40.80; YoYo Jam
http://yoyonation.com/product.php?productid=16843
PHOTO: STEVE KOLOSKI

that thrives on new tricks that can be thrown only on new yo-yo designs.

Using his computer-aided design, manufacturing, and machining expertise, Kaiser created what became the first General-Yo product, the Torrent, released last December.

Built with aerospace-rated bearings, the Torrent could spin in place at the end of the string (known as "sleeping") for minutes at a time. Thanks to precision machining, it balanced well for tricks that could only be described as a kind of fast-moving, ultra-dynamic combination of juggling, plate spinning, and cat's cradle.

"I thought about what makes these things tick," Kaiser says. "I tried to put the weight as far out on the diameter as possible and put a very small axle on the inside, [making it] very hard to machine."

Kaiser made only 60 Torrents; they sold out in six weeks. In March, a new design, the 5-Star, sold out in one day. A second-generation 5-Star also quickly sold out.

For the holidays, Kaiser will be coming out with a new model, the Hat Trick, which will also be a limited release and undoubtedly a sellout as well.

A leading yo-yo retailer, the A2Z Science and Learning Store (http://a-two-z.com), recommends two new yo-yos that have similar specs and street cred—albeit without the aerospace-geek pedigree.

YoYoJam's New Breed, designed by national champion yo-yoer Eric Koloski, also boasts a wide body and long sleep times, which make it well suited for the catalogs of tricks chronicled on sites like Yoyoexpert.com and Yoyonation.com.

The YoYoFactory's 888 features two inner bearing-mounted wheels on either side ("hub stacks") that expert yo-yoers can grab to hold the yo-yo without stopping it from spinning.

—Mark Anderson

888 $119.99; YoYoFactory;
http://shop.yoyoexpert.com/manufacturer/3/YoYoFactory

ROBOGOLF

You don't have to putt like Tiger Woods to practice like him

If you think there's still too much walking around in golf, even with a golf cart, you need the RoboCup and Caddy Cord, a ball-return robot and a missed-putt return guide.

RoboCup, which won Best New Product at the 2009 PGA Merchandise Show in January, works on any practice green. When your putt drops into the hole, a springboard device automatically shoots the ball right back. It runs on four AA batteries, which should be good for 12 000 putt returns of up to 4 meters.

The Caddy Cord, made of a flexible double-braided nylon cord, wraps around the back of the hole, sending the ball along the cord and back to the hole, where the RoboCup can return it.

RoboCup and Caddy Cord
US $59.95; Fine Tune Golf
http://www.finetunegolf.com

"The Caddy Cord also provides feedback on your putting stroke," says Keith Foley, RoboCup's inventor. Putt too hard and the ball will jump over the cord; putt too short and your ball won't get returned. "This encourages a proper putting distance, rewarding you with the returned ball," he says.

Mike Dugan, a golf professional in Kissimmee, Fla., says his students "become fascinated with the RoboCup and are motivated to make more putts so the ball will return to them."

—Susan Karlin

gifts

hands on

If You Build It, Santa Will Come

Kits for building musical pencils, theremins, crystal radios, and shortwave radios

WHAT BETTER way to introduce a young person to the joys of engineering than by giving a gift that you construct together? I tested four suitable kits. Two are for unusual electronic musical instruments, and two are for dabbling in radio.

Drawdio
Adafruit Industries; US $17.50; http://www.adafruit.com/index.php?main_page=index&cPath=28
PHOTO: RANDI SILBERMAN KLETT

The Drawdio turns a pencil—or a pencil sketch—into a musical instrument that sounds something like a kazoo. The kit, available from Adafruit Industries, costs just US $17.50, takes only an hour or so to assemble, and includes everything you need but the AAA battery. If you have any experience soldering components to a printed-circuit board, assembly will be a snap. The hardest step is pushing a thumbtack (included) into the end of a pencil (also included) to make electrical contact with the graphite that runs down its center.

Drawdio is simply an oscillator whose frequency is controlled by the resistance of the circuit path connecting the part of the pencil you grip with the attached thumbtack. You can make sounds by grabbing the pencil in one hand and touching the tack with the other, but that's not the fun way to use it. Instead, draw a heavy line, laying down a lot of conductive graphite as you go. Then press on one end of the line with the forefinger of your free hand while holding the tip of the pencil on the other end of the pencil line. Apply adequate pressure, and Drawdio will emit a low buzz. Moving the tip of the pencil closer to your finger reduces the resistance of the frequency-control path, shifting the sound to a higher pitch. So it's not hard at all to generate a simple tune. If you have trouble hitting the right notes consistently, just mark their positions on the line.

If you really want to impress a musical protégé, splurge on a kit for a theremin, the granddaddy of all electronic musical instruments, whose eerie, melancholy sound is a hallmark of old science-fiction movies.

Thanks to the late Robert Moog, a pioneer of electronic music, you can buy the Etherwave Theremin kit, available from Moog Music for $359; many online distributors sell it for less. The kit includes a fully assembled printed-circuit board, so all you have to do is wire up the front panel and two antennas, which sense the position of the player's hands, thus controlling pitch (right hand) and volume (left).

Etherwave Theremin Kit
Moog Music; $359; http://www.moogmusic.com/theremin/?section=product&product_id=18
PHOTO: RANDI SILBERMAN KLETT

The Etherwave kit comes with a handsome oak cabinet, but I was disappointed by the sloppy fit between the top and bottom pieces. Most of my effort went into rebuilding the cabinet. Check your kit and send it back if the woodwork is botched.

That shortcoming aside, this kit is a joy. The theremin, unlike most instruments, has no keys or frets for your fingers to land on. Hitting the right note is quite tricky because you have nothing but your ear and an eyeball estimate of the distance to the pitch antenna to guide you. Like chess or Go, it takes minutes to learn and a lifetime to master. I quickly rendered a recognizable "Mary Had a Little Lamb," all the while chuckling at the notion of playing music without having to touch the instrument. My goal is to master "Over the Rainbow," which should keep me busy for some time yet. Fortunately, the kit's copious documentation includes a video on theremin-playing technique.

The Little Wonder Crystal Radio Kit
Xtal Set Society; $16.95; http://www.midnightscience.com/kits.html
PHOTO: RANDI SILBERMAN KLETT

Those less musically inclined might prefer kits for radios. You could, for example, put together a classic crystal set, which in a bygone era would have involved an actual crystal, probably a lump of pyrite or galena. In most of today's inexpensive kits, a diode serves as the detector, and a few other components complete the bare-bones radio circuitry, which drives a high-impedance earphone with nothing other than the energy picked up by the antenna.

To explore such a simple project, I purchased The Little Wonder Crystal Radio Kit from the Xtal Set Society for $16.95. It took only minutes to assemble, and it worked right off the bat. But its performance is so underwhelming—mine could pick up only one local station—that I worry a young person would be turned off by the experience.

I recommend instead Ten-Tec's model 1253 nine-band receiver kit, which you can order directly from the manufacturer for $89. It spans from 1.8 to 22 megahertz and thus picks up both shortwave and ham bands. What's more, because it has a regenerative detector, it has excellent selectivity and can receive AM, single-sideband, and continuous-waveform broadcasts. The front-panel controls include frequency, RF gain, and audio volume, as well as a somewhat mysterious regeneration adjustment. You can have hours of fun tuning in to the world by twiddling these dials. It's not often you can share in an experience that pretty much went out of fashion decades ago.

This kit is very well designed and has an excellent set of instructions, though most people will require a good weekend of work to get it all put together. The hardest part for me was learning to use the regeneration control after I finished assembly. Initially, I was disappointed with how few stations I could pull in. Then I got the hang of delicately adjusting the amount of feedback used in the detector—something you don't do on modern radios—and the world opened up with nothing but a 5-meter wire antenna draped over some furniture in my living room.

The radio is housed in an attractive enclosure, and it has a built-in speaker as well as an earphone jack. It can run off batteries or a wall wart (neither is included). All in all, it's much more than a demonstration project—you end up with a very practical radio set.

If none of these kits tickle your fancy, search the Net for others that do. Exposing a young person to the feeling of having built a piece of electronic gadgetry is well worth the occasional dud. Hopefully, it'll spark wonder yet demystify electronic technology. And *that* would be the best gift of all.

—*David Schneider*

Model 1253 Nine-Band Regenerative Shortwave Receiver Kit
Ten-Tec; $89; http://store.tentec.com/kits/receivers/#1253
PHOTO: RANDI SILBERMAN KLETT

Dam It!

A new science kit brings hydropower to the playroom

THE CENTURIES-OLD practice of using moving water to do work is now enjoying a resurgence as the world weans itself of fossil fuels. Enterprising kids can bring hydropower to their Lego and other playroom constructions by building the Hydropower Renewable Energy Science Kit, by Thames & Kosmos.

This kit, the latest in a line of hands-on guides to alternative energy, is billed for kids 8 and up. Earlier kits include Wind Power, Fuel Cell, Power House, and Global Warming.

There are tubes and straws for some fun experiments involving water towers and fountains that you can make from plastic bottles. But the main events are three different toy mills built around a water wheel. One moves a "saw" back and forth, one repeatedly lifts a "hammer" a few inches and drops it, and the third—the coolest—creates enough electricity inside a small DC generator to light a red LED.

Each experiment took about an hour of assembly and debugging time—mostly the latter, as even older folks will look at the pictorial instructions and scratch their heads over exactly where the anchor pin or gear-shaft rod should go. One more slight criticism: The single electronic component could have been a little less flimsy.

That said, when the hydropower station was finally working and the bathtub water turned on, this reviewer and his 3-year-old were thrilled to see that tiny red diode light up—a beacon of sustainable power for the next generation.

—*Mark Anderson*

Hydropower Renewable Energy Science Kit
Thames & Kosmos; US $49.95; http://www.thamesandkosmos.com

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careers

FLYING HIGH? Record orders for commercial aircraft are helping the aerospace industry weather the current recession.
PHOTO: TOM SHEPPARD/GETTY IMAGES

AEROSPACE JOB FORECAST: SKIES ARE CLEARING

Long-term contracts buffer the aerospace-engineering market

Construction crews are working on the first commercial spaceport, in New Mexico. Start-ups are rushing to launch tourists and cargo into space. Google wants to put robots on the moon. The commercial space race is on—and it's helping the broader aerospace industry.

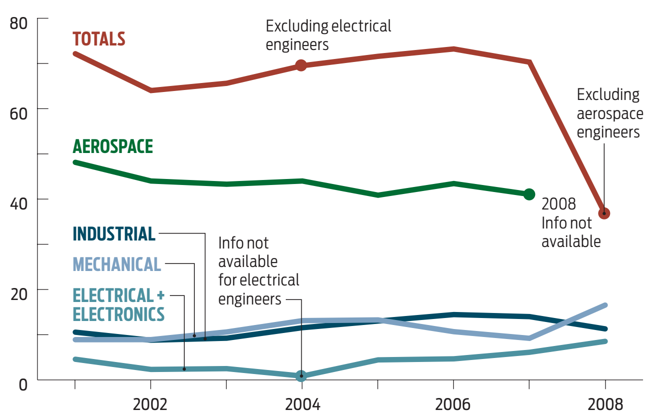
It can use the help. The layoffs that followed the economic crash have left fewer jobs for engineers than there were in 2008. But a backlog of orders combined with an increasingly urgent need to replace an aging workforce has cushioned the blow.

Multiyear contracts are why aerospace withstands recessions better than other tech sectors. Current aerospace projects date from several years ago, and many have years to go, says Jeremiah Gertler, assistant vice president of defense policy at the Aerospace Industries Association (AIA). "That's why there's still lots of work and big backlogs."

The low point came in 2003, as the commercial side of aerospace dipped in the wake of the 9/11 attacks. By 2008, the industry had added back 70 000 jobs as increases in defense spending kicked in. "We've had record orders for commercial aircraft, plus we're at war," says Carole Hedden, who conducts a workforce survey for *Aviation Week & Space Technology*. Numbers decreased slightly in the last quarter of 2008 because of a 57-day Boeing machinist's strike that started in September. And, Hedden warns, the effect of the general economic downturn on the sector's job market hasn't been measured for 2009 yet.

Private space enterprise, the development of commercial aircraft like the Boeing 787, and NASA's moon-to-Mars mission have added job opportunities, says Wei Shyy, chair of the aerospace engineering department at the University of Michigan, in Ann Arbor. Jobs in government have increased, he says, but "the number of new hires doesn't seem to come close to that in the private sector." Marc Williams, associate head of Purdue University's aeronautics and astronautics school, in West Lafayette, Ind., says that in his program's 2007 graduating class, the ratio of corporate job takers to those who took government or military jobs was 3 to 1.

ENGINEERING JOBS IN AEROSPACE PRODUCTS AND PARTS (THOUSANDS)



Source: Bureau of Labor Statistics

Aerospace companies are now looking for engineers—particularly aerospace engineers, only half of whom work for companies making aerospace products. But according to the Bureau of Labor Statistics and the AIA, demand within the aerospace sector for electrical and electronics engineers has increased even more in the last five years.

There is a desperate need for fresh talent. In 2005, 55 percent of working aerospace engineers were over 45 years old, Shyy says. *Aviation Week's* 2008 workforce survey reported that 19 percent of engineers and computer scientists in the industry qualified for retirement in 2007. Similarly, Matthew Knowles, spokesperson for the Society of British Aerospace Companies, says that in the United Kingdom's aerospace and defense market—the second largest in the world—there are many skilled engineers approaching retirement age, yet demand is undiminished.

The sector's delayed reactions to current events make it tricky to find the right time to change jobs. In any case, your skill set may ultimately determine how easy it is to get hired. Last year, engineers with radio-frequency expertise and hardware- and software-engineering skills were in especially high demand. But for all engineers, aerospace is a sector worth exploring. "Neither the government or private aerospace industry is getting the people they need," says the AIA's Gertler. "There are plenty of jobs out there we still need to fill."

—Prachi Patel

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reflections BY ROBERT W. LUCKY

Engineering Achievements: The Two Lists

IN A speech to engineers about taking pride in our profession, I mentioned two lists of engineering achievements put together by the National Academy of Engineering. The older list ranks the 20 greatest engineering achievements of the last century. The newer list consists of 14 grand challenges to be accomplished by engineers in the present century.

As I walked out of the banquet hall, someone muttered, "I liked the old list better." That offhand comment started me thinking. I remember helping to put that list together. The achievements chosen and their rankings were based on the relative importance of their benefits to society. Electrical engineering figured prominently: fiber optics and lasers, household appliances, imaging, the Internet, telephones, computers, radio and television, electronics, and of course electrification itself. The new list has such challenges as securing cyberspace, preventing nuclear terror, advancing health informatics, making solar energy economical, reverse engineering the brain, and enhancing virtual reality.

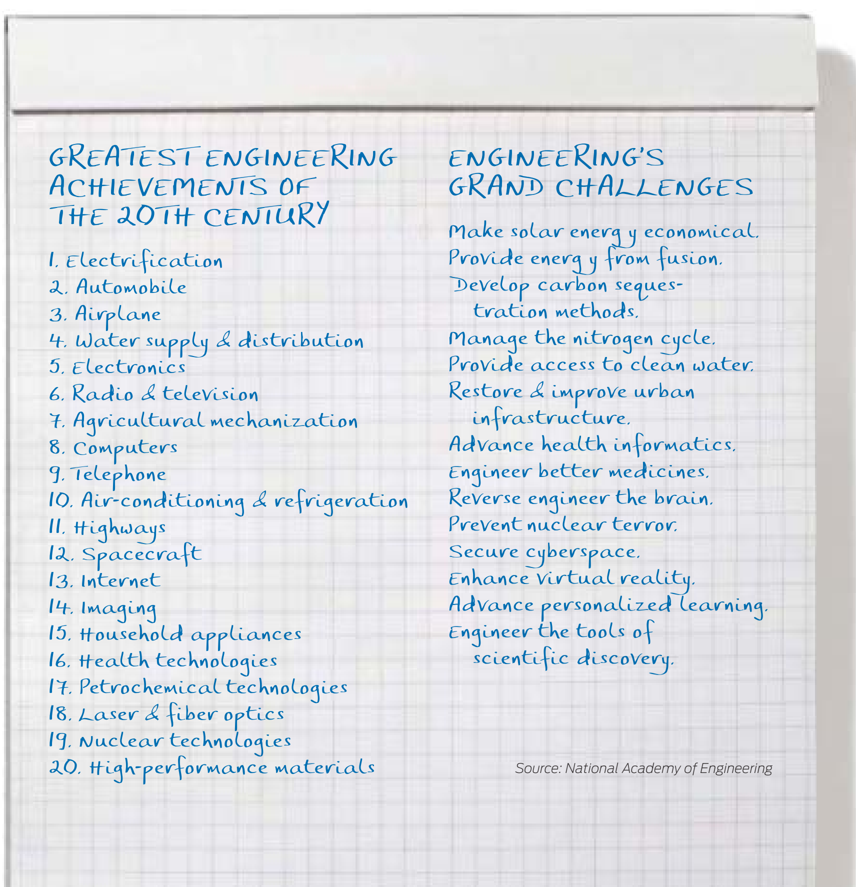
What strikes me now about the old list is that, although each achievement resulted in sweeping societal changes, it began with an invention in the classic sense, made by a small number of inventors, that focused on solving a relatively narrow problem. Moreover, the invention itself was a discrete *thing*, as opposed to a large system or collection of ideas. For example, the transistor was developed in order to implement better telephone repeater circuits. The Internet was originally intended to transfer files between mainframe computers, and it was thought that the computer itself would have only a small market consisting of large organizations with special needs.

Similar things could be said about most of the other achievements on the list. The automobile wasn't designed to populate the suburbs, air-conditioning wasn't invented to increase the size of cities in hot climates, and household appliances weren't developed to enable more women to join the workforce.

This is the way it has always been. Small, discrete, thinglike inventions—the printing press, the steam engine, the cotton gin, the electric light, and so forth—change society in ways that go far past the plans and expectations of the inventor. In contrast, the new list turns the paradigm upside down. An important social benefit is postulated, and engineers are challenged to make an invention, or more likely a system, that accomplishes the designated social upheaval.

This is not to say that the upside-down approach cannot be effective. I would hope that the new generation of engineers will be motivated by opportunities to improve the world, and I do believe that most of these challenges will ultimately be met. However, I also think that the challenges will be met by cross-disciplinary teams of relatively unknown people developing large systems, policies, and procedures.

When the history of this century is written, I wonder what a list of great engineering achievements will look like—and will we associate specific inventors with them? Is the era of brilliant, discrete inventions by individuals coming to an end in favor of systemic, planned social engineering by large teams? I regret that few if any of us now will ever know. ❏



STEVE WISBAUER/GETTY IMAGES

Z I N K

A Modern Fairy Tale

BY TEKLA S. PERRY

A magical new technology has risen from Polaroid's ashes: inkless printing with colorless color

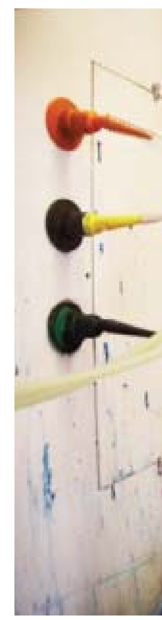
Major innovations in printing don't come around very often. The last one was the inkjet printer, in 1976. And now there's Zink, a full-color printing technology that does away with a messy, expensive annoyance that consumers have learned to hate: ink.

THE COLOR MAKERS: *Brian Busch [left], Stephen Herchen [center], and J.C. Van Dijk were among the 50 who left Polaroid to form Zink.* PHOTOGRAPHY BY JOSHUA DALSIMER


ZINK
ZINK
ZINK

Zink's first generation of printers was really only a novelty, spitting out prints measuring 2 by 3 inches (about 5 by 8 centimeters), but its second generation, which is only now rolling off assembly lines, allows formats of 4 by 6 inches (about 10 by 15 cm). That's enough to crack the key home-printing market. And the technology is still very young.

The story of Zink is not just one of a unique technology. It's about engineers and scientists pursuing a dream deep within a corporate research laboratory, long after most companies came to view research as a luxury they could do without. It's a story of how those researchers stayed true to their dream, even as the venerable corporation whose 70-year-old brick walls sheltered them drifted into bankruptcy. The story even has a Madoff-like Ponzi scheme that sent key investors to prison. It truly is a modern fairy tale.



ONCE UPON A TIME, in a 40-year-old company called Polaroid, a young Cambridge, Mass., chemist named Stephen Herchen began working on his first project. It was 1977, and instant photography was booming, led by Polaroid's SX-70 camera, introduced in 1972. Herchen was one of 25 scientists and engineers working in a laboratory that focused on projects without timelines or product goals.

Herchen's task was to take a look at a specific approach to instant photography that would get around a drawback of the SX-70 process, which was based on dyes that migrated up through an opaque screen to become visible. Because such diffusion is hard to control, the photographs had limits to their resolution. Herchen's assignment was to find chemicals that started off colorless but could transform, with exposure to light, to the yellow, cyan, and magenta pigments necessary for a full-color photo. Because they'd be colorless, there'd be no need to hide them with a screen and therefore nothing through which they'd have to diffuse.

Colorless colors? It sounded like a task for Merlin. Herchen worked on the problem for about 10 years without solving it. Finally, he dropped the idea and turned to making better chemicals for traditional dye-diffusion films, contributing to the Spectra film introduced in 1986.

Then, in the 1990s, digital photography began eating away at the instant photography market, and Polaroid started scrambling. In the labs, researchers turned to developing printers for this new type of photography. They took two approaches—one intended to develop a high-speed thermal-transfer process for use in photo kiosks, code-named Opal, the other to create a portable printer, named Onyx, for consumers. Both were huge efforts and quickly became the main focus of the laboratories, with more than 100 researchers assigned to each.

Herchen became Polaroid's vice president of R&D and chief technical officer in 2003, overseeing these projects. It wasn't a happy time. Even though the photo-kiosk prototypes were well received, the collapse of instant photography dragged the company down. Polaroid cropped its staff even further, down from a peak of 20 000 to fewer than 6000.

Juan C. Van Dijk, a mechanical engineer who was working in product development at the time, recalls "trying to throw every kind of analog camera at the wall to see if something would stick. We had new high-end instant cameras. We had a low-end camera with a hand crank instead of a motor that was supposed to sell for US $9.99. We were really desperately trying to have something succeed."

But the ones and zeros of digital photography trumped the chemistry of instant photography. In 2001, Polaroid filed for Chapter 11 bankruptcy.

MEANWHILE, IN THE LABS, the researchers on the Onyx portable printer began to think about a new approach—or rather an old one. Printing with the dye-transfer process, as used in commercial photo kiosks and portable photo printers, was slow and cumbersome: The print actually had to make four passes through the printer, one for each of the three colors

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and one for an overcoat. It had to stay precisely aligned as the motor moved it back and forth. And the printer needed yet another motor to move the ribbon when required. (Inkjet printing moves the printhead instead of the paper, also a complicated mechanical process.)

It occurred to everyone on the Onyx and Opal teams that the trouble lay in applying the different colors. What if the colors were somehow already in the paper, waiting to be turned on, the way phosphors are on a TV screen? It came back to the colorless-color problem that Herchen had tried and failed to solve. He'd been trying to create color that could be activated by light, but that hadn't worked out—it was simply too difficult. But in the meantime, heat-activated color had become as common as a cash-register receipt. These devices used printheads full of tiny resistors that applied pulses of heat to paper, not so different from the printheads used in the dye-transfer device. No one was doing full-color photographic printing using heat-activated color, but that didn't mean it wasn't possible.

It was time to get Polaroid's electrical engineers and physicists involved. Brian Busch, a Ph.D. physicist who'd been working at the company for about four years, was the first to tackle the printhead problem. It was an exciting time, Busch recalls: "There's the feeling of being the core of the team that's working on the new thing, the future, the project that is going to save the company. And there was an incredible spirit of teamwork. I didn't want to let down the chemists who had worked so hard to come up with these brilliant molecules that perform their magic so reliably. All I had to do was to get this obstreperous piece of hardware to produce some heat and melt the dye."

IT WASN'T ALL that simple. Busch and the two dozen engineers who worked with him on the hardware module needed to rethink the operation of thermal printheads. Existing thermal printers dealt with just one color at a time, so their resistors simply had to be hot or not. But the Onyx team needed to control three colors, and they intended to do it in a single 30-second pass across the printhead. Their idea was to fine-tune those colorless colors to activate at different temperatures, then precisely control the printhead to deliver the right amount of heat for the right amount of time for each of the 300 dots in each square inch of the print.

Busch calls it the "fried ice cream" approach, conceived by Polaroid

SECRET SAUCE: *Zink's magic starts in a chemistry lab, where scientists build unique molecules, lay them onto paper, and then apply heat to turn them from colorless to colorful.*

The single-color heat-sensitive papers already on the market used two colorless chemicals that formed a color when they merged. Single substances involved much simpler chemistry, which was important given the complexity already inherent in getting three colors in one paper. So the chemists in the company began developing single substances that were colorless in their solid crystalline state but intensely colored when melted out of crystal form, staying colored when cooled.

It took nearly three years to find chemicals that could produce yellow, cyan, and magenta. The next problem was how to control them; if you put all three colors in a single sheet of paper and used heat to activate all of them equally, you'd end up with mud.

researcher Stephen Telfer, now head of Zink's chemistry and media development groups. "How do you melt a high-temperature molecule without melting a low-temperature one? With fried ice cream, you roll it in dough and throw it in really hot oil for a short amount of time. The coating fries without melting the ice cream because you're hitting the shell with a high temperature, but the heat doesn't get to the ice cream." But if you want to melt the ice cream without cooking the dough, he says, just leave it on the counter overnight, and "the low temperature over a long time will melt the core."

Fried ice cream was the answer to the colorless-color problem. The color closest to the surface—the one with just the right melting point turned out to be yellow—would have the highest melting point and the shortest pulse. That way the heat wouldn't have time to migrate down to the next color (magenta), which has a medium melting point. The longest pulse would heat the third color (cyan), which was deepest down, but because it was at a low temperature, it wouldn't affect the other two.

Busch and his colleagues worked on control electronics for the thermal printhead, precisely adjusting the time and temperature of the 200 million pulses of heat needed to make a 2- by 3-inch print. They came up with pulses of about half a millisecond for the yellow and about 10 ms for the cyan.

The chemists continued to tweak their colorless compounds, trying to adjust the melting temperatures to 200, 150, and 100 °C, low enough to protect the plastic coating but high enough to prevent the colors from being activated if the photo was left in the sun.

The team solved the puzzle by adapting the approach being used over in the Opal photo-kiosk project. The Opal researchers were also using heat, but instead of trying to melt the dyes directly, they embedded the dyes with solvents and used heat to activate the solvents. The Onyx team realized it was much easier to find a solvent that melts at the right temperature than to engineer a colorless molecule that responds to that temperature. The solvents then melt the colorless crystals into puddles of colorful ink.

On Christmas Eve 2001, it all came together. The group printed its first recognizable image using a thermal printhead wired to a field-programmable gate array chip. They'd proved the concept.

The reaction within Polaroid was mixed, recalls Van Dijk. "It was a disruptive technology—so disruptive that it would have killed camera sales. It would have killed instant film. So there was hesitation about going full speed ahead with it."

Meanwhile, Polaroid's business troubles continued. In July 2002, an investment firm, One Equity Partners, purchased the bankrupt company. The strategy was like buying a foreclosed house; the new owner would hang onto the company for a while, perhaps renovate it a little, and then try to sell it at a profit.

In April 2005, One Equity sold Polaroid to a Minnesota businessman, Thomas Petters, for an undisclosed amount. Petters immediately began using the Polaroid brand name on a line of digital cameras.

Petters wasn't interested in continuing the Onyx research. "He was excited by the technology," says Herchen. "We were able to do some pretty neat things with it, and it wasn't that far off from being a product." But continuing the research—the team then had 100 people on it—would have cost millions of dollars a year.

Petters gave the team six months to find a buyer or investor. A major inkjet-printer company was interested, and the team focused on making that acquisition happen. In May of 2005, though, the inkjet company backed out. Petters made it clear that he could not support the Onyx group after the end of June.

"It was time for a Hail Mary pass," says Herchen. He and Busch, the physicist, got on a plane for Japan. Recalls Busch, "We packed our bags and a soldering iron and a couple of crude prototype printers, and in two weeks we did dozens of demos in Japan and China and Korea."

"We put our paper into the cassette, and we could print images," Herchen says. "They weren't as high quality as they needed to be [for a commercial product], but they were very, very good, and they showed promise."

Most of the executives they met with simply listened politely, then bowed farewell. "The companies basically said, 'Yeah, okay, fine, come back to us when it's really working,'" Busch says.

Until they got to Alps Electric.

Alps Electric Co., based in Tokyo, makes thermal print engines and printers for a number of well-known consumer electronics brands and ships thermal print engines to countless other printer manufacturers. By the mid-2000s, the 20-year-old technology was, by any definition, mature.

HOW THE MAGIC HAPPENS

TOP LAYER *A short pulse of heat, at 200 °C, turns the top set of crystals yellow.*

MIDDLE LAYER *A longer pulse of heat, at 150 °C, activates the magenta crystals.*

BOTTOM LAYER *And an even longer pulse, at just 100 °C, creates the color cyan.*

PAINTING WITH HEAT
In the hands of an artist, Zink paper takes on new dimensions.

SIEGFRIED HOLZBAUER

The Alps executives may have reached the end of the road in optimizing it when Herchen and Busch landed on their doorstep.

"We took out our little printer—which was one of theirs—yanked out the ink ribbon cartridge, and said, 'How would you like to see me print without that? Look at this space you could eliminate—all of the mechanisms and parts and motors and things that are used to move the ink ribbon—you're not going to need that. You could make this half the size,'" Herchen told them. "'And there's going to be no more of this four-pass process with each color printed in its own pass. We're going to do it all in a single pass,'" a much faster proposition.

He hit the button and made the print. Within a week, Alps had signed on as a major strategic partner. It would develop and manufacture printheads and print engines using the Onyx technology and serve as an original equipment manufacturer to consumer-products manufacturers. Back in the United States, an investor named Robert Dean White offered to fund the spin-out of the Onyx team into a private company that would continue to develop the technology and manufacture and sell the paper. The team had beaten their deadline.

Back in Massachusetts, however, it wasn't all champagne and flowers. For while White's investment had managed to keep the project from drowning, it wasn't going to be enough to support a team of 100 to profitability.

"It was a bit like Noah's ark," recalls Herchen. "We needed something of everything, some number of people who knew mechanical engineering, some who knew electrical engineering, firmware, software, molecular design, synthesis, physics, chemical engineering. We had to figure out the smallest number of people we could take that could cover all [that]."

He took 50 out of a staff of about 100. The choice was brutal, as was the announcement. "I had two meetings," says Herchen, "one with a group of 50 telling them that we hoped they would come with us, and another with a group of 50 telling them they wouldn't be able to do that. These were great people I'd worked with for years and years." The researchers that wouldn't be boarding the ark packed up their things and left that day. And on 1 October 2005, Zink Imaging incorporated.

YES, THAT'S ZINK. Not Onyx—that was just a code name—or Chromonyx, which briefly followed Onyx. And not iCMY, an attempt at merging i-coolness (the *i* stood for "inkless") with an acronym for cyan, magenta, and yellow—which during a period of frustration came to mean "I can't make yellow." The development team had realized that the coolest thing about their technology was that it required no ink. So they named the technology Zero-ink, or Zink.

The new company gave an equity share to each of the 50 who made the leap from Polaroid. As part of the spin-out agreement with Polaroid, Zink took just about everything connected with the project, from the electron microscopes to the pencils on the desks, for a fraction of its value. It also walked away with a portfolio of 100-odd patents.

With the money from White, some additional investment from Petters, and, in 2008, an infusion of funds from Mangrove Capital Partners, of Luxembourg, the group continued to develop their technology into a product. Both the chemistry and the electronics needed continual tweaking. Getting the color green to print cleanly, recalls Busch, was a particular nightmare, because it required activating the yellow top layer and the cyan bottom layer without affecting the magenta layer sandwiched in between. Researchers also had to engineer a top coating for the paper—one that would act as a lubricant when the paper ran through the printer, then as a protective sealant when the print was complete. And they needed to develop a system to make sure that when the software directed the printhead to produce a particular color, the right color would appear on the paper.

Their solution was to include a rough piece of paper, imprinted with a bar code, in every pack of paper. This addition cleans the pathway and enables the printer to calibrate itself, for each batch of paper has a slightly different sensitivity that must be compensated for to maintain color accuracy. The first generation of printer engines, with an image size of 2 by 3 inches (about 5 by 8 cm), came out early this year; the next generation, boasting images of 4 by 6 inches (about 10 by 15 cm), is due to ship in the fourth quarter of this year. The company is already testing prototypes of a version measuring 8 by 10 inches (about 20 by 25 cm). So far, Polaroid, Tomy, and Dell are selling products based on the Zink technology.

Zink's success depends just as much on the paper as it does on the hardware. Of course, the hardware needs to be out there to sell the paper, but the paper is Zink's core business. Initially, the Zink researchers made their paper, in sample quantities, on a pilot manufacturing line in the lab. But by November of 2005, they realized they needed a real manufacturing operation. Two months later, they picked one up for a song. William Keating, a Zink senior vice president, heard that Konica Minolta Holdings, a joint venture that made paper for professional photo minilabs, was getting out of the business and closing its Whitsett, N.C., factory.

"We asked them to stop the auction and give us the time to see if this was a fit for us," says Wendy Caswell, now the chairman and CEO of Zink. It was. Zink purchased the factory and all the equipment in it at what Caswell considers an incredible bargain. "It was a win-win. They didn't have to lay their people off, which mattered to them, and Zink acquired a state-of-the-art manufacturing facility and a team to operate the plant."

BY SEPTEMBER OF 2008, things were running pretty smoothly. Zink had solid financing from an established venture firm. It had its first consumer-electronics partners ready to introduce products in early 2009. It had been producing paper for several months.

And then, on 3 October, White and Petters, Zink's original investors—and at that time, board members—were arrested in Minnesota, charged with mail fraud, wire fraud, money laundering, and obstruction of justice in a scheme that had defrauded investors of some $3.65 billion. (Bernard Madoff's Ponzi scheme would grab even bigger headlines two months later.) At press time, Petters was expected to go on trial in October. White pleaded guilty and faces up to 22 years in jail.

Caswell heard of the arrest on the morning news. She spent the day working with the Mangrove team, and by that evening, Petters and White were off the Zink board and the company was on its way to being restructured to dilute the pair's ownership to an insignificant amount, insuring that Zink and its assets would not be affected by any legal proceedings. It's not exactly clear where the money the two invested into Zink came from, but Caswell says it doesn't matter to the company's future.

Today Alps is producing Zink print engines. Foxconn Technology Group and Lite-On Technology Corp., both of Taipei, Taiwan, are building Zink-based products for major consumer-products companies. Four Zink products are already on the market—the Polaroid PoGo printer, the Polaroid PoGo camera, the Tomy Xiao camera, and the Dell Wasabi printer, ranging in price from $35 for stand-alone printers to $200 for an integrated camera printer. Zink paper sells for about 30 cents a sheet. The company expects to sell to both consumers and businesses. On the consumer side are all the traditional users of photography. On the commercial side are insurance agents and police, who need to staple a photograph to a report instantly, fashion photographers, and decorators, as well as photo kiosks, medical offices (for color-coded labels), and commercial signage (Zink's images are water-resistant).

And the Zink technology is catching on among artists, much as the old Polaroid technology did, back in the day, and for the same reason—you can alter the colors while the photo is developing.

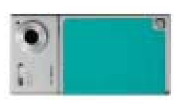
The company, now based in Bedford, Mass., has 100 employees. At this writing, 49 of the original 50 who left Polaroid remain; the 50th left to do missionary work in Bolivia. The company is winding up a final round of venture funding and expects to be operating in the black by early 2010.

People, Caswell says, have "an inherent hatred of ink. 'Ink costs so much,' they say. 'It runs out at the worst time possible. It's messy. The jets clog. Then I have to blow through ink to unclog them.' The technology has decades to go; we don't know today all of the applications for it."

Perhaps on the moon or Mars—zero-ink printers work just fine in zero gravity. ❑

ALREADY ON THE MARKET

POLAROID POGO *This $200 camera has a built-in Zink printer.*



TOMY XIAO *This camera and printer package is available only in Japan.*

DELL WASABI *This $35 printer can receive images wirelessly.*

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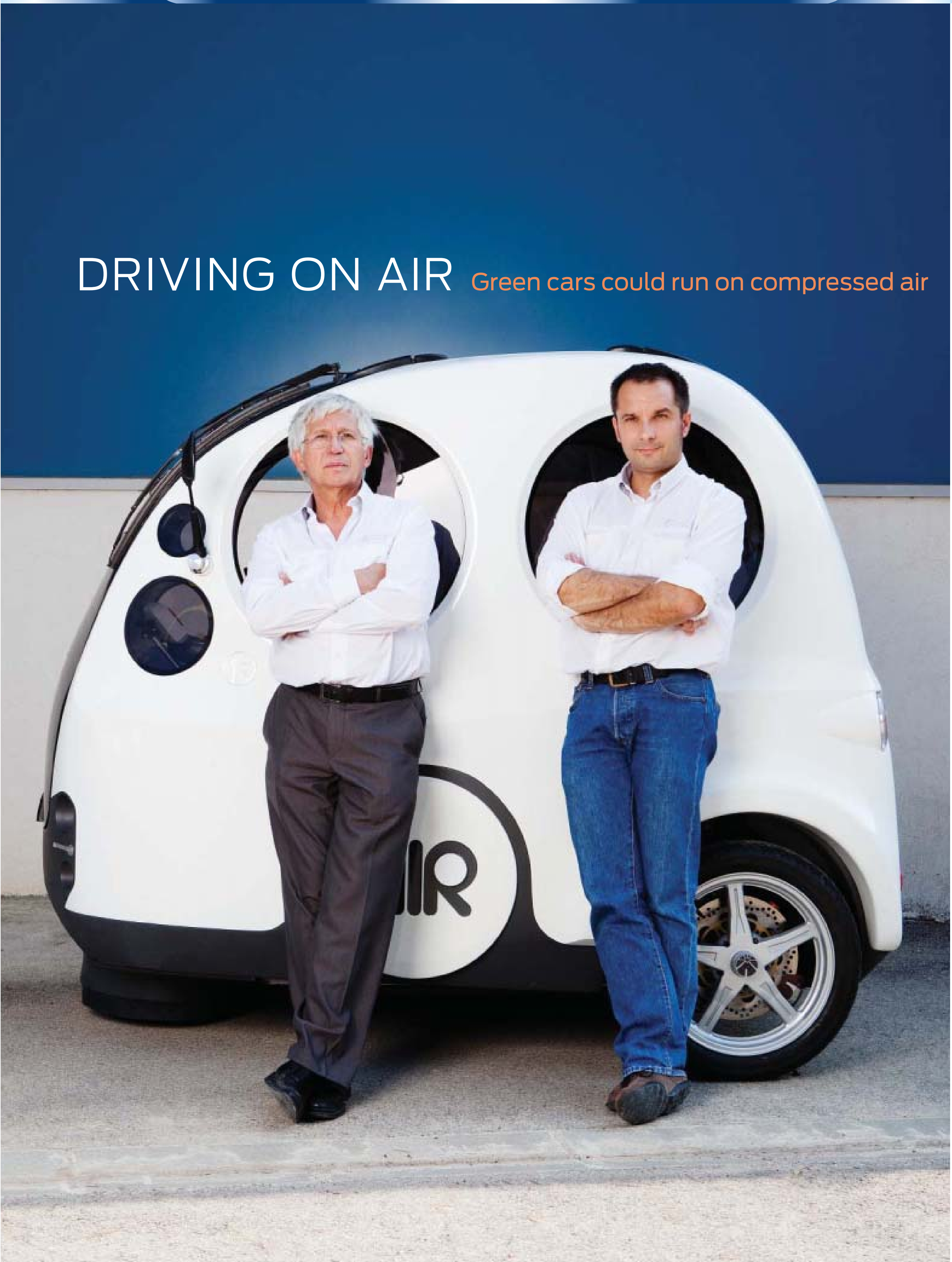
DRIVING ON AIR

Green cars could run on compressed air



instead of batteries. But don't rely on the new AirPod minicars to prove it

A NEW CELEBRITY WITH A LUSCIOUSLY CURVED BODY is turning heads on France's Côte d'Azur. No, not that kind of body. This one belongs to the AirPod, a 220-kilogram car with a sculpted composite shell and a back-to-the-future energy supply: 80 kg of air compressed to 350 times sea-level atmospheric pressure, roughly 350 bars. The engine of this tiny three-seater converts that air into mechanical energy, just as a pneumatic jackhammer does to blast apart concrete.

The AirPod won't exactly tear up the road, though: The current version tops out at 45 kilometers per hour (28 miles per hour). And yet there's definitely something addictive in its joystick steering and featherlike suspension. With expanding air pumping its pistons, the exhaust is literally a superchilled breeze. Grab the stick, step on the accelerator, and any guilt you may be harboring from driving an ordinary smog-producing carbon spewer falls away. Wouldn't life be great if everybody got around town in these clean little machines?

BY PETER FAIRLEY PHOTOGRAPHY BY VINCENT LIGNIER

This rosy vision of future urban transport is the product of Motor Development International (MDI), a company registered in Luxembourg whose tech-chic atelier lies in Carros, a palmy industrial suburb of Nice, France. Guy and Cyril Nègre [opposite], the father-and-son team behind MDI, predict their technology will find mass appeal in the emerging city-car category, an automotive segment of small, efficient cars well suited for crowded European and Asian cities and not meant for long-haul trips.

Most carmakers think that battery power is the future for this category, but the Nègres beg to differ. The AirPod, they promise, can tank up in just 2 or 3 minutes using no more than 1.5 euros' worth of France's nuclear-heavy, low-CO_2 electricity to provide some 220 km (137 miles) of city driving. It has no batteries to wear out and replace—and so will cause no worries about its power source ever erupting in flames. And the AirPod will cost a mere €6000, the Nègres say (less than US $9000).

Storing energy in a long-lasting pressure tank made of carbon fiber rather than in batteries, posit the Nègres, makes the AirPod cheaper, more practical, and cleaner than a comparable electric vehicle (EV), once you take manufacturing and disposal into account. It's a bold assertion, and one that remains to be proved, which won't be possible until these cute little cars actually hit the road. And when that will happen is anyone's guess.

Though the AirPod is supposed to go on sale in a couple of months, the Nègres have been struggling to commercialize pneumatic vehicles for more than a decade, incurring a reputation for unfulfilled promises. No independent testing laboratory has assessed the AirPod's performance. And while deals over the past three years with India's Tata Motors and Paris-based Air France

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POD SQUAD: Workers at Motor Development International are busy readying AirPod prototypes at the company's fabrication facility near Nice, France. Viewed from underneath its curvaceous shell [left], the AirPod reveals an aluminum frame, which encloses a composite tank holding air compressed to 350 bars [middle]. A steering wheel would be impractical, because the driver's door is located at the front of the vehicle. The solution is a joystick placed next to the driver's right hand [right].

have bolstered MDI's credibility, it remains tough to find an automotive engineer who buys into the company's vision. The fundamental problem, they say, is the laws of thermodynamics, which make compressed air an impractical power source for vehicles. The AirPod's 200-liter tank is roughly the size of a common 55-gallon drum, but it carries the energy of little more than a liter of gasoline. And its air-powered engine makes inefficient use of it. MDI counters that the ultralight, low-speed AirPod needs very little to get around. Yet skeptics abound.

"I don't know how they can deliver what they claim," says Denis Clodic, a mechanical engineer and thermodynamics expert at France's prestigious École des Mines de Paris. "It's not a solution for the sort of vehicle we expect today," says Pascal Higelin, professor and director of the Mechanics and Energy Laboratory at the University of Orléans, in France.

And yet Higelin and Clodic count themselves among the growing number of propulsion authorities who say that vehicles combining compressed air and fuel combustion could overcome the primary drawbacks of both, providing an economical alternative to today's gasoline-electric hybrids. The greatest impediment to realizing such pneumatic hybrids, according to these two experts, is that the failure of MDI's air car could cast doubt on the whole idea.

So if the AirPod does whoosh onto French streets within months as promised, there will be quite a bit more riding on the quirky little runabout than MDI's fate. It could finally prove the viability of compressed-air transport—or doom it for the foreseeable future.

Pneumatic propulsion was high tech in the late 19th century, when compressed-air engines and equipment became commonplace in Europe and North America. Networks of compressed-air piping vied with then-nascent electrical grids to power machine tools, railway hoists, and switchyards, among other heavy gear. Meanwhile, the first jackhammers were revolutionizing mining and tunnel construction. Propulsion uses included pneumatic torpedoes, locomotives, and streetcars. Addison C. Rand, founder of Rand Drill Co., lauded pneumatic streetcars in his 1894 guide *The Uses of Compressed Air*, noting that they had neither the "distressing, jerky motion" of cable cars nor the capital costs of electric railways.

Combustion-powered automobiles and buses ultimately prevailed, as we all know. But a vestige of air propulsion survives in today's Formula 1 racing pits, where blasts of air crank the big engines to life, and it is from this world that Guy Nègre emerged. The self-taught mechanic studied philosophy and worked in French carmaker Renault's advertising department in the 1960s before setting up his first engine-design shop. There Nègre developed an unusual valveless engine for light aircraft, a design that was never commercialized. Nègre's second shop extended the valveless concept to powerful Formula 1 race-car engines. In 1990, a racing club installed Nègre's engine for the storied Le Mans 24-hour endurance race. But the engine refused to start, let alone endure for 24 hours. This firm, like the one before it, slid into obscurity.

In 1991, Nègre made the intellectual 360 that led to the AirPod. Together with his son Cyril, then an engineer for Bugatti Automobiles, Nègre formed MDI to develop low-emissions engines, and by 1996 they had locked onto air propulsion. While both father and son's names are listed on the firm's patent filings, Cyril is officially the R&D director, and Guy is the president, responsible for selling their vision.

The "thermo" of thermodynamics—the unstoppable flow of heat—makes pneumatic propulsion a considerable engi-

TRICYCLE GEAR: Behind the driver are seats for two passengers [top left]. Tanking up [top right] takes just a few minutes. At left, a test car hits the streets.

neering challenge. The molecules of oxygen, nitrogen, and other gases in air give off heat when compressed, representing a loss of energy up front. Do the compression quickly, before the heat can dissipate into the surroundings, and the losses rise further. And the trouble only mounts when all this compressed gas is later released from the tank. The same molecules cool when they expand, hence the chill on your hand when you empty a spray can. Expand the gas slowly, and the pneumatic equipment can stay warm by reabsorbing energy from the atmosphere. But power-hungry vehicles must expand the gas quickly, so they are subject to extreme cooling, which hampers the engine or, at worst, freezes its air-feed lines.

By the late 1990s, MDI was talking up a first-generation engine it claimed could handle these complications. Its design would expand air in three stages, maximizing the opportunity to absorb heat, just as efficient multistage gas compressors maximize heat dissipation. The firm used this design to raise money, selling franchises for the local production and sale of its vehicles and raising expectations. For example, the sale of the first such franchise—rights to the Mexican market—sparked press reports that smog-choked Mexico City would soon mandate MDI's "zero-pollution" technology for its 87 000-strong taxi fleet.

By 2000, production was slated for 2002. In 2002, it was to begin in 2003. Indeed, commercialization was always just around the bend. But the promised vehicles never arrived. Icing of moisture in the air-feed lines, the pneumatic equivalent of plaque-choked blood vessels, sapped efficiency and output. And the system was impractical to mass-produce. "We could reach good efficiency with that [design]. We had ideas for how to do it. But it was complex," admits Guy.

From 2003 to 2007, MDI was dead in the water. Debts mounted while the staff contracted, from a high of 50 employees down to 12. What saved the firm was a simpler engine conceived in 2005 and now being readied for the AirPod. In January 2007, Tata Motors purchased the Indian rights to MDI's technology for an undisclosed sum, widely reported as $30 million, repairing both the firm's finances and its tarnished reputation. "It was clearly the patents, the designs for the new-generation [motor] that convinced Tata to link up with us," says Guy.

MDI's second-generation design drops two of the three stages of expansion and is thus simpler and more robust, the Nègres argue. The key to efficiency, they say, is its pair of specialized, interconnected cylinders [see diagram, "Double Duty"]. Air released from the tank is allowed to expand to 20 bars before being fed at constant pressure to the first cylinder, which MDI calls the active chamber. When the active chamber's piston reaches full extension, a valve attached to the air inlet closes. Only at this point is the air allowed to expand, pushing its way into the second, larger cylinder. Because the pressure in the active chamber is constant when the air valve is open, the valve and air-feed lines don't overchill. Only as the larger cylinder's piston moves does the air expand enough to reduce the temperature past the freezing point—well past it:

Turbocharging the Turbocharger

ALTHOUGH pneumatic engines are problematic for vehicular propulsion, storing compressed air on board a car can boost the efficiency of a normal combustion engine enormously. The idea is to use the engine to compress a small volume of air during braking, then feed that high-pressure air back to the cylinders during acceleration to increase the amount of fuel they can burn, sending more power to the wheels. As is the case with gasoline-electric hybrids, this strategy allows a car to get by with a smaller engine. Lino Guzzella, a professor in the department of mechanical and process engineering at the Swiss Federal Institute of Technology, in Zurich, has recently developed such a pneumatic hybrid engine [left] with support from Robert Bosch, a German manufacturer of automotive components.

Guzzella describes his engine as an improvement on normal turbochargers, which compress air for extra power using energy recovered from exhaust gases. That can leave drivers waiting for several seconds while the compressor's turbine comes up to speed, a phenomenon called turbo lag. "You step on your pedal and nothing happens. The more you downsize [the engine], the more pronounced this turbo lag will be," says Guzzella. In contrast, he says, his pneumatic hybrid leaps to life instantly, thanks to the electromagnetic valves Bosch developed and the ultrafast controls Guzzella has engineered. "From one combustion cycle to the next you can go from idle to full load. This is faster than any other combustion engine ever built," he boasts.

"It's a relatively minor and low-cost modification to a conventional engine with the potential to give fairly significant efficiency increases," says Doug Nelson, a professor of mechanical engineering at Virginia Tech. The gain in normal driving is roughly 30 percent, according to Guzzella's modeling. That's shy of a gas-electric hybrid's performance, but Guzzella bets that his strategy will have a greater impact on global fuel use: "Gasoline-electric hybrids make sense for affluent societies, but the really big global challenges are in places like China, India, Southeast Asia, and Africa," he says. "People there cannot afford a $30 000 car." —*P.F.*

During the exhaust stroke, the frigid air is expelled to the muffler at –40 to –70 °C. "Once the valve is closed, you can cool [the air] a lot, because if there is ice it will go to the exhaust," says Cyril.

By the end of 2007, Guy was once again promising imminent commercialization, gearing up for production of a city-car sedan. But MDI shifted course in January 2008, when the mayor of Paris announced plans to station thousands of rent-by-the-hour city cars around town. The competition to provide such eco-friendly personal transportation would be fierce, but the rewards to the winner could be great. So Guy dreamed up the AirPod as a pneumatic entry in that contest. Anticipating a quick road-certification process, because this featherweight minicar doesn't exceed the 500-kg threshold for requiring crash testing in the European Union, MDI decided to throw its resources at the AirPod.

"That's what MDI needs: to get a car on the market," says Cyril.

The AirPod made quite a splash when it was unveiled in October 2008. It was then that the mayor of Nice, who also leads the local regional authorities (and, in a peculiarity of French democracy, serves in President Nicolas Sarkozy's government as well), committed the city and region to testing compressed-air vehicles and, perhaps, to using them in a Niçoise version of the Parisian car-rental scheme. A week later, Air France and affiliate KLM signed up to test half a dozen AirPods in their maintenance hangars.

Guy insists that within the first few months of 2010 MDI will have its first assembly line at Carros churning out one AirPod per hour while he and his son are coordinating the creation of three more assembly plants set up by European licensees.

Could the AirPod be the vehicle that finally makes good on pneumatic propulsion? Analysis of performance specs that MDI supplied to *IEEE Spectrum*—among the first released by the firm—suggest that the vehicle's range may be less than a third of the 220 km (137 miles) claimed. But with gasoline prices expected to rise along with global temperatures, even that modest distance may be sufficient to interest buyers.

According to MDI's figures, the 80 kg of compressed air in the AirPod's tank has the potential to generate 11.2 kilowatt-hours of mechanical energy when fully expanded at constant temperature—a truly best-case scenario. The engine's minimum operating pressure of 10 bars will leave a few kilograms of air in the tank, trimming total usable energy to 10.8 kWh. The process of expanding the air before it is sent to the engine, however, gives this figure a lot more than a trim: Dropping the pressure from 350 bars to 20 bars before the air can be fed to the cylinders wastes nearly half the stored energy. So that leaves just 5.6 kWh to spin the AirPod's wheels. MDI vows that the production version of its engine will somehow do better, providing 6.2 kWh of mechanical energy where the rubber meets the road. "We know what to do," Guy says. But the firm's best effort to date passed just 4.4 kWh to the wheels, he concedes. Because the AirPod requires 2.8 kWh to travel 100 km on a standard European urban driving cycle, the numbers indicate that its range can be only about 160 km.

But even that figure sounds unrealistically high to outside experts. Clodic of the École des Mines, for example, estimates that the engine's limited efficiency will provide only 1.9 kWh of usable mechanical energy for a maximum range of 68 km (42 miles).

The efficiency stats look even worse when you include the energy cost of filling the AirPod's tank. MDI says its plant's compressor is 58 percent efficient, near the top end for commercial units. Using MDI's numbers, this means that the AirPod's plug-to-wheels efficiency is currently just 23 percent. That makes an unflattering comparison with the lithium-

PHOTO: ETH ZURICH

battery-powered EVs approaching the market, such as Mitsubishi's iMiEV subcompact car, which is expected to operate at three times that efficiency.

The Nègres argue that although lithium-ion-powered EVs can beat the AirPod's efficiency by a large measure, they make for unrealistically expensive cars. A lithium battery for the AirPod would cost almost as much as MDI will be asking for the entire vehicle. Most city cars on the market today use cheaper but heavier and less efficient lead-acid batteries. As a result, estimates MDI, those EVs actually suck more energy from the grid for each kilometer traveled than does the AirPod. Doug Nelson, an expert in hybrid vehicles at Virginia Tech, in Blacksburg, can't confirm that assessment, but he agrees that pneumatic vehicles could be a winner for the city-car segment if lithium batteries remain too pricey.

The promise of a cheaper form of clean transport is indeed what convinced Air France to consider AirPods, according to Jérôme Bouteyre, the airline's director of facilities management. EVs that Air France has tested as runabouts for its maintenance crews cost between €15 000 and €35 000—a steep jump up in price from vehicles of similar size with internal combustion engines, which can be had for less than €10 000. So the AirPod is economically competitive with conventional vehicles of this sort, and critically, it meets Air France's modest needs—according to Bouteyre, a top speed of 30 to 40 km/h and a range of 10 to 20 km per day.

Motorists, however, have come to expect much more from their cars. That's why some of MDI's critics think that automakers should be focusing not on air-powered cars but on pneumatic-fuel hybrids. Unlike cars running on compressed air alone, the greater power available from pneumatic hybrids would suit full-function, highway-capable vehicles. And compared with today's hybrids, whose battery-equipped drivetrains cost three times as much as an ordinary gasoline engine, pneumatic hybrids could be priced for economy shoppers and for the developing world. "We have a system that provides 80 percent of the benefit and costs maybe 20 percent extra," says Lino Guzzella, a professor of mechanical and process engineering at the Swiss Federal Institute of Technology, in Zurich.

DOUBLE DUTY: The AirPod's engine uses two linked cylinders. Compressed air flows into the smaller cylinder first at a constant pressure of 20 bars [1]. When the smaller piston bottoms out, the intake is closed, and the air in the small cylinder expands, flowing into the larger cylinder [2 and 3]. Both pistons then move to exhaust the expanded air [4], and the cycle begins again.

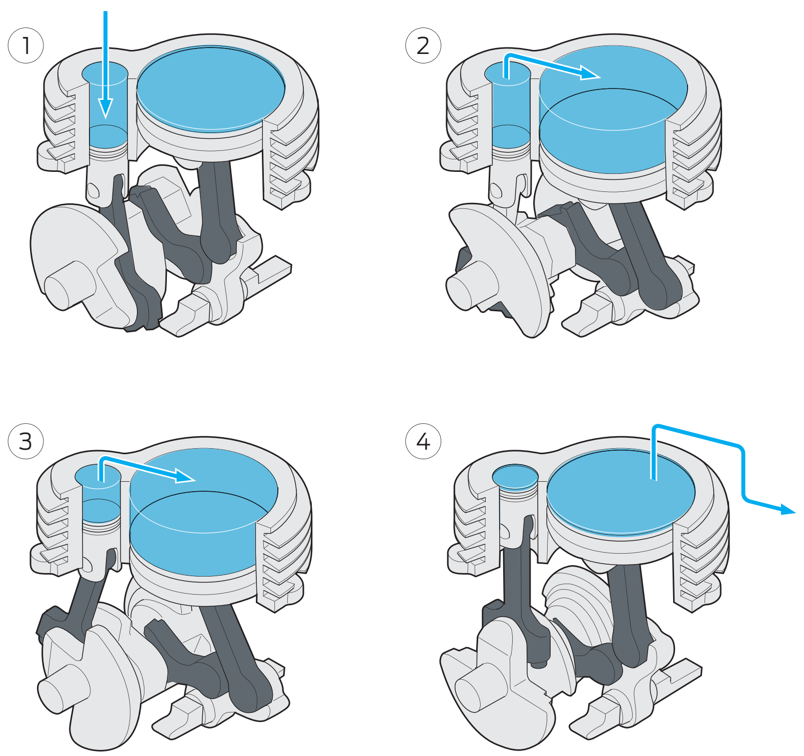

ILLUSTRATION: JASON LEE

With support from German auto-components giant Robert Bosch, Guzzella is testing small engines that use a 20- to 30-L compressed-air tank to rival the performance of power plants twice their size. That tank is filled with air pressurized to 20 bars using braking energy or spare engine power. In this novel variation on conventional turbocharging, that high-pressure air is then fed back into the engine along with extra fuel to deliver precise bursts of power. "We are able to burn the fuel in a much more efficient way," says Guzzella [see sidebar, "Turbocharging the Turbocharger"].

MDI is working on an even simpler hybridization scheme, first successfully employed in 1901 to extend the range of pneumatic torpedoes. The idea is to add a small fuel burner upstream of the engine to warm the air released from the tank, increasing the air's volume and thus reducing the amount required to charge the cylinders. MDI claims this dual-mode system will triple the AirPod's range, while consuming just 0.56 L/100 km of gasoline (420 mpg). Clodic, however, questions whether MDI possesses the discipline and resources to see this hybrid system through.

MDI's prospective industrial partners, Tata Motors and Air France, seem to have a wait-and-see attitude. Air France, which originally expected to begin testing AirPods in May and was still awaiting delivery as this article went to press, isn't worried, according to Bouteyre: "Either it's built and corresponds to our requirements, or it's not and we won't try it. We have nothing to lose." The head of corporate communications for Tata Motors, Debasis Ray, says his company is licensed to use MDI's technology in India, "only as and when it gets ready. We are not engaging beyond this at this point in time."

Guy's response to the skeptics? He says that there is no such thing as a truly independent expert for assessing novel vehicles: "The only evaluation possible is on the road." True enough, but that's only an option if others can acquire examples of the finished product. And in all the time that MDI has been working on vehicles, no product has emerged. In the computer industry that's known as vaporware, an appellation that seems oddly appropriate for a car that runs on air. ❑

TO PROBE FURTHER To see an online slide show surveying other micro-size cars, go to http://spectrum.ieee.org/micro_cars.

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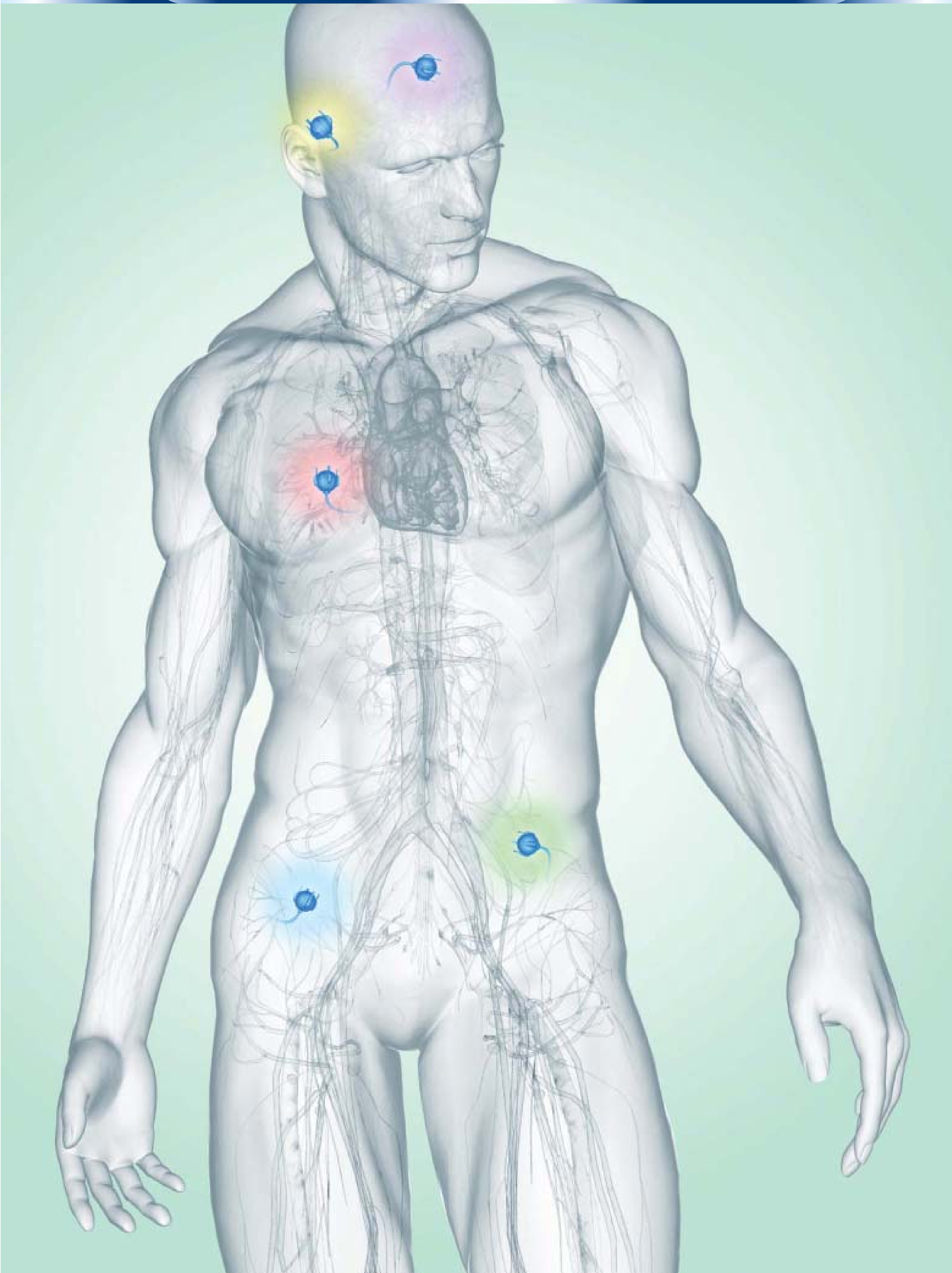


MEDICINE BY MICROMACHINE

FLEXIBLE MICROSYSTEMS ARE ENABLING DRUG-DELIVERY IMPLANTS FOR THE HUMAN BODY

BY JEFFREY T. BORENSTEIN

The bedrock of modern medicine is an age-old technology: the pill. For the most part, it works. The drug inside the pill finds its way to whatever part of the body it's meant to treat, and the patient recovers. ¶ But sometimes, oral medications just aren't effective. The medication may interact with other drugs or food. It may break down in the stomach before entering the bloodstream. Or, even more frightening, it may trigger other, bigger problems even as it aims to cure. Recall the painkiller Vioxx, which did wonders for arthritis patients but also raised the risk of heart attack and stroke. Or Baycol, a cholesterol-lowering medication that was linked to dozens of reports of fatal kidney failure. In one way or another, traditional oral medications fail hundreds of thousands of patients each year, according to the U.S. Food and Drug Administration. ¶ For years, researchers have searched for better ways to deliver drugs. The ideal method would administer the right dose to the exact area being treated, whether it's an arthritic knee or a tumor in the lungs. From the patient's perspective, it would be both convenient and unobtrusive—as easy as, if not easier than, taking a pill.

BRYAN CHRISTIE DESIGN

My collaborators and I are pursuing that better way. The implantable drug-delivery device we are developing at the Charles Stark Draper Laboratory, in Cambridge, Mass., and at the Massachusetts Eye and Ear Infirmary (MEEI), in Boston, merges aspects of microelectromechanical systems, or MEMS, with microfluidics, which enables the precise control of fluids on very small scales. Unlike rigid implants, such as pacemakers or titanium hips, our device is a flexible, fluid-filled machine: Stretchy tubes expand and contract, and fluids flow in and out of channels according to a preset rhythm. A tiny pump acts as the machine's heartbeat, and software lets the device adapt to new demands from its environment.

Microscale machines are nothing new, of course. For the last four decades, engineers have built them for a variety of purposes, harnessing the mechanical properties of silicon and the same assembly techniques used to manufacture microchips. The resulting MEMS products now appear in all kinds of consumer electronics, such as air-bag sensors, inkjet printers, and the tiny accelerometers inside Nintendo Wii controllers.

Microsystems may have a much greater impact, however, in biomedical engineering. Engineers and clinicians have dreamed up a whole world of assistive devices that could enhance, sustain, and prolong human life. But these health-care innovators are stymied by one key constraint: the difficulty of making the devices small enough to sit comfortably and unobtrusively inside the body. Microscale systems built not from silicon but from flexible, stretchy polymers could be the answer. And to take that one step further, our implantable device may be the first therapeutic MEMS machine to include the active control of fluids.

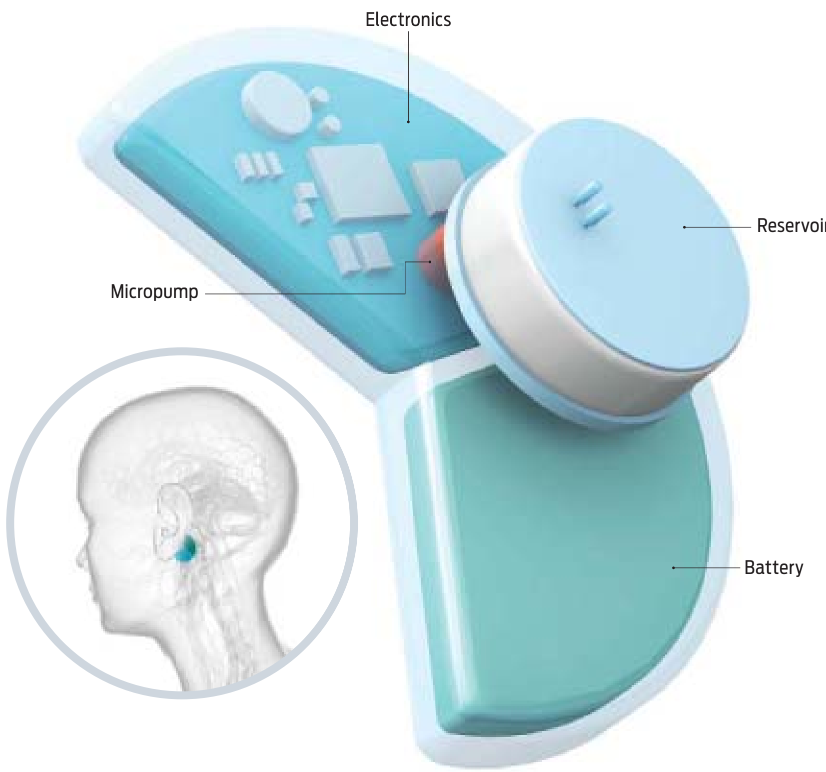
The polymer MEMS device my colleagues and I are developing, with funding from the United States' National Institutes of Health, will treat the most common form of hearing loss, which now affects more than 250 million people worldwide. By delivering tiny amounts of a liquid drug to a very delicate region of the ear, the implant will allow sensory cells to regrow, ultimately restoring the patient's hearing.

Our system, which is still under development, consists of a programmable micropump powered by a small battery and controlled by an electronic circuit. It pulses precise quantities of a drug from a small reservoir into the inner ear. A flow sensor meters the delivery and sends out an alert if anything goes wrong. What we have so far is about the size of a D-cell battery, but we're working to get it down to the volume of a single AA battery, which ought to be small enough to suit most patients. The device's reservoir would hold enough medication for about one year. We've already tested the system on guinea pigs, and our results show that it can successfully deliver medication to the inner ear without damaging hearing.

At our current pace of progress, we could see clinical use of such drug-delivery systems in the next five years. Eventually we intend to extend the uses of our system to treat a number of other diseases. Keeping track of medications can become impossible for the elderly and those with neurological or psychiatric conditions, and their doctors never know how closely these patients are following their medication schedules. A tiny, programmable electronic system that delivers the proper drug dose at exactly the right time would clearly benefit patients and caregivers and would also ease the burden of patient monitoring on medical personnel and hospitals. Indeed, this work could revolutionize medical care.

DO WE REALLY NEED to replace the simple act of swallowing a pill with complicated, invasive electronics? Yes—for many diseases and conditions, pills are either ineffective or unsafe. The human body has a number of defense mechanisms that will attempt to outsmart invading foreign substances like drugs. A drug, when swallowed, travels through the bloodstream to circu-

EAR GEAR Once it has been fully miniaturized, our implantable drug-delivery device may end up resembling a "UFO" in shape. It will hold enough medication to last a patient about one year, after which the patient would undergo a minor procedure to refill the reservoir. The final device will be about the volume of one AA battery. *ILLUSTRATION: BRYAN CHRISTIE DESIGN*



late widely. Doctors must often prescribe a higher dose than would otherwise be necessary if the drug could be delivered directly to the spot where it's most helpful. Sometimes that higher dose is also more toxic.

Another challenge is that not all parts of the anatomy are in direct contact with the bloodstream. As a result, many conditions, including hearing loss and several neurodegenerative diseases, can't be treated effectively with oral or injected medications, The blood-brain barrier, for instance, is a thin layer of endothelial cells lining the blood vessels in the central nervous system that prevents contact between the bloodstream and the brain. A similar blood-cochlea barrier protects the ear. A device implanted directly into a hard-to-reach target, however, could circumvent these blockades.

We aren't the first to explore implantable drug delivery. Nonelectronic implantable systems are now used to treat brain tumors that can't be surgically removed. In such cases, the tumor is typically treated with a drug called BCNU, which is effective but also highly toxic. In 1987, Robert Langer, a chemical engineering professor now at MIT and a pioneer in the field of drug delivery, and his colleagues Henry Brem of Johns Hopkins and W. Mark Saltzman, now at Yale, came up with the idea of encapsulating the drug in a biodegradable polymer wafer and surgically implanting it in the brain. As the polymer slowly dissolves over a period of weeks to months, the BCNU is released and delivered directly to the tumor. Studies show that, on average, the treatment extends patients' lives by several months at least, and they avoid the severe side effects—such as anemia, liver problems, and lung damage—that can occur when the drug is taken by injection. Similar passive systems have also been developed into drug-delivery patches for treating nicotine addiction and motion sickness and for birth control.

The dissolvable wafer was a landmark development, but not all ailments respond to its passive functions. In the cochlea, for example, injected medication and drugs in controlled-release gels would not travel far enough without the assistance of a pump. The wafer also has a limited life span; an electronic delivery device, by contrast, could operate for years and be programmed to deliver multiple drugs of varying dosages at different times. Several teams of engineers are now developing implantable drug-delivery systems to treat pain, neurological diseases, cancer, and many other conditions. One leading system is the "pharmacy on a chip" being developed by MicroChips, in Bedford, Mass., also founded by Langer and his colleagues. This drug-delivery microsystem has spurred the development of other implantable delivery devices, including our own microfluidic approach.

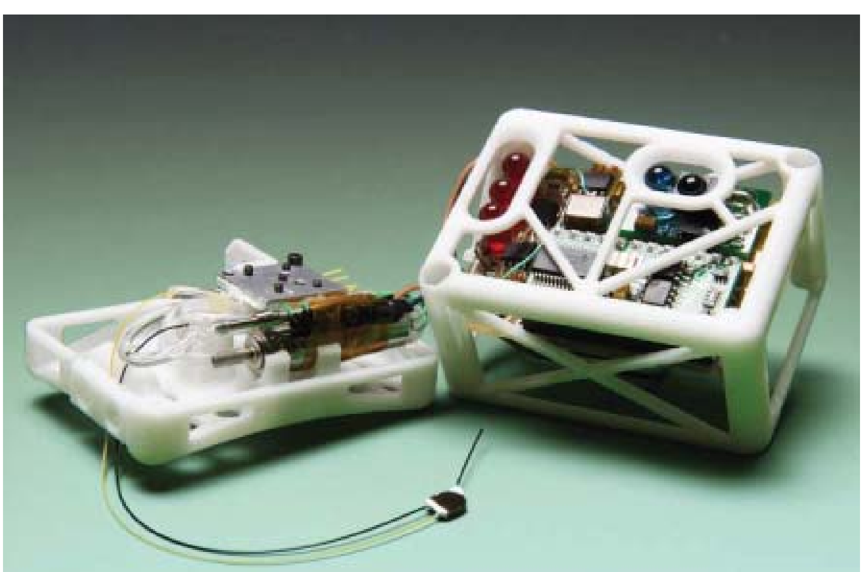
We've focused our work on hearing loss because it is so widespread and because existing treatments don't offer a cure. In sensorineural hearing loss, the most prevalent form, the tiny, sensitive hair cells inside the organ of Corti, a structure within the cochlea, can be damaged or lost, which means they would no longer function normally as receptors of sound. The disease has several causes, including exposure to excessive noise or toxic chemicals, genetic factors, or simply aging. In addition, roughly three in a thousand children in the United States are born with significant hearing impairment, making it one of the most common disorders at birth.

The only therapeutic interventions available to these individuals are hearing aids and cochlear implants. Hearing aids amplify sound, but they don't always make the sound clearer. Cochlear implants bypass the damaged cochlea altogether to electrically stimulate auditory nerve fibers. Neither device can halt or slow the loss of hearing.

Once thought to be irreversible, sensorineural hearing loss may soon be treatable with drugs. Clinical researchers and biologists are rapidly accumulating insight into the molecular signals involved in generating new hair cells. One approach involves inserting genetic material into the nuclei of hair cells, with the hope of restoring their function.

Delivering therapeutic compounds to the ear, though, is no small task. Any drug-delivery system for the ear will require extremely high-precision engineering to navigate the intricate internal geometry of the cochlea. This structure contains a coiled, snail-like tube with a membrane that's covered with sensory elements and stretched across the middle of the tube. The membrane moves in response to sound, and hair cells sense the shearing forces of that motion. Fluid, called perilymph, bathes many of the functionally important elements of the cochlea, including the hair cells.

Despite the cochlea's peculiar and complex environment, the system we've built is quite simple. Our



DOSE ON DEMAND: The 2007 version of the device [above] uses a traditional pump and is about the size of a D-cell battery. A smaller, push-pull system is under development.
PHOTO: CHARLES STARK DRAPER LABORATORY

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approach is to drill a single inlet hole in the scala tympani, one of the perilymph-filled cavities of the cochlea, and insert a small tube. A highly efficient, electronically controlled pump about the size of a pencil eraser will push the drug out of its reservoir through a network of valves and channels. The drug will travel through the tube, and the pump will help mix the drug with the inner ear fluid. Sensors in the device will detect the fluid flow and transmit that information to an external receiver, which will monitor the performance of the implant.

THE DEVICE'S DEFINING FEATURE is its fluid circuit. Just about every introductory electrical engineering course uses the analogy of water flowing through a pipe to explain the basics of circuit design. We've taken the reverse approach, using electrical circuit elements to model the fluid-dynamic behavior of the drug-delivery system and the ear. Critical parts of our model include the resistance to flow both in the delivery device and in the cochlea, the compliance (or stretchiness) of the device and the cochlear membranes, and the driving force that the micropump must deliver to the flow.

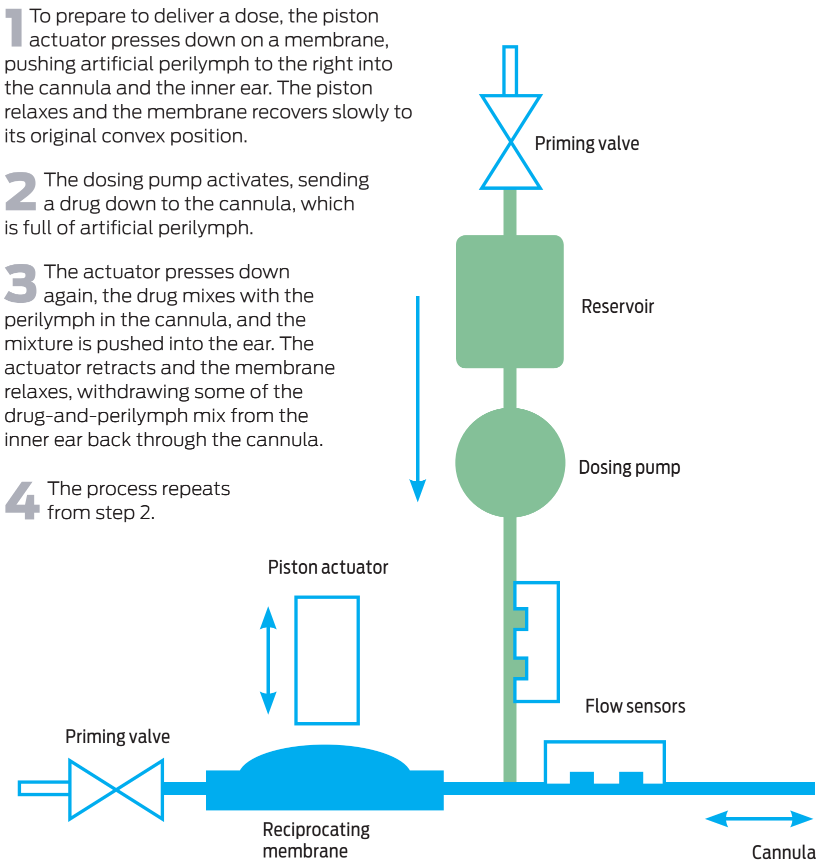
If a tube or vessel has some elasticity, energy can be stored in the expansion and contraction of the vessel's walls, giving it a storage function comparable to electrical capacitance. So we model compliance using a capacitor. Modeling the resistance to flow in a pipe or tube is very straightforward: We use an electrical resistor analogue. The flow rate of a fluid in a pipe is analogous to the flow of current. The driving force for fluid flow—the micropump—acts like a voltage source, or power supply. The micropump generates a pressure difference between the drug reservoir and the inner ear by working against the fluidic resistance and using the storage capability of the tube's elasticity to drive the drug into the cochlea. In our model, the resistance and capacitance of the overall system includes values for inner ear structures, which are fixed, and values for our device, which can be tuned.

All of this is important because the cochlear structures in the inner ear are extremely sensitive to forces and flows. We need to provide just enough flow to deliver sufficient quantities of a drug far enough down the spiral tube. Too much flow could damage the ear, and too little would have no therapeutic effect. The resistances and capacitances within the device determine how much flow is generated by the pump and how quickly the drug is delivered to the cochlea. In other words, we can choose a particular diameter and length of tube to achieve a specific resistance and a particular elasticity to impart a specific capacitance. To tailor the timing and magnitude of doses, we can vary the intensity of the flow and the frequency of the pumping by programming a microcontroller in the device.

When we started building our device, we initially worked with silicone rubber materials that are prevalent in microfluidics, namely Silastic tubing and PDMS (for polydimethylsiloxane) components. These materials are transparent, inexpensive, and simple to fabricate, and they are generally suitable for contact with biological fluids and tissues. They also stretch nicely and therefore are excellent capacitor structures for the device. But we soon discovered a problem: The materials are permeable to air and liquid, and tiny air bubbles, barely visible to the eye, were forming inside the narrow tube that carries fluid into the cochlea. The tube is narrower than a human hair, so even a very small bubble can completely stop up the system. The air bubbles ended up acting as capacitors in our circuit, and they became an uncontrolled and unsta-

THE PUSH-PULL METHOD

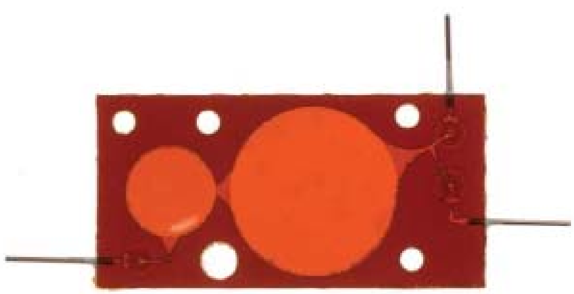
The key element of our implantable device is this push-pull mechanism, which injects a drug deep into the inner ear without flooding the ear and causing damage. The device uses two fluids—the prescribed drug and artificial perilymph, which mimics the natural fluid in the inner ear.



ble element in the design—sort of like having a frayed wire in intermittent contact in a circuit.

To avoid the bubbles, we switched to a less familiar material, polyimide, for most of our polymer components. It's much less permeable to air and water, and we coated the remaining permeable materials with impermeable surface layers. Of course, there was a trade-off. Most microfluidics research is done with PDMS, and engineers typically mold and cast PDMS by micromachining a silicon wafer, pouring the liquid polymer into it, and peeling out a replica molding. But micromolding polyimide is impractical, so we now use laser machining to build our micropump.

With the new materials in place, we immediately faced another challenge. The total volume of perilymph in the human cochlea is only about one-fifth of a milliliter, and so very small changes in fluid volume or pressure can damage the hair cells and other delicate structures. To avoid causing any damage, we implemented a "push-pull" system in which the drug is infused into the perilymph and then an equivalent volume of fluid is withdrawn from the cochlea, thereby maintaining a constant volume. To give the drug a chance to mix with the perilymph, we use a low-resistance, low-capacitance component to release the drug and a high-resistance, high-capacitance element to extract the fluid. That translates into a relatively rapid drug infusion pulse and a much slower and gentler withdrawal pulse. The dosage can be programmed to be constant over time, but more complex dosing profiles and combinations of multiple drugs are also possible.



FLUID CIRCUIT: A piston compresses a chamber [left] to pump a drug reservoir [right], in this 2.5- by 1.3-centimeter element.
PHOTO: CHARLES STARK DRAPER LABORATORY

The push-pull system has an added advantage that has nothing to do with the cochlea's twisted passages but everything to do with why implantable medical devices often fail. Anything that gets inserted into the body undergoes a process known as biofouling, which occurs when a foreign object triggers an inflammatory response from the body. Our concern was that fouling could potentially slow or stop the pumping action. But our system isn't static (unlike most implants), and we believe that minimal fouling will occur, because the pushing and pulling would break up any cellular or protein build-up before it becomes permanent.

OUR CLINICAL COLLABORATORS at MEEI have tested a version of our drug-delivery system on guinea pigs. Many compounds with known effects on hearing exist, and we are using these formulas to evaluate our system.

So far, the results have been very encouraging: We were able to circulate a liquid drug well into the depths of the cochlea, and we found that the fluid manipulations didn't harm the guinea pigs' ears. Even more compelling were our experiments in which we deliberately modulated their hearing. We started by infusing about 1/1000th of a milliliter of a test compound into a guinea pig's ear through a catheter that had been surgically implanted. The catheter's inner diameter was 100 micrometers, or about the width of a human hair, and it was connected to a pump and control system worn by the guinea pig. We then withdrew roughly the same quantity of fluid, now mixed with the perilymph, and repeated the infuse-withdraw cycle for several hours.

One of the beautiful things about working with the auditory system is that the exact location in the cochlea at which a sound is perceived depends on the sound's frequency. High-pitched sounds register near the entrance of the cochlea, while low-pitched sounds are perceived much deeper inside. (One octave equates to about 3 millimeters of cochlear tube.) To test how effective our device is at delivering a drug, we can fill the device's reservoir with a drug that has a temporary dampening effect on hearing and begin pumping it into the subject's ear. When we observe that the drug is deadening only high-pitched sounds, we know that the drug has reached the entrance to the cochlea. Once the subject stops responding to low-frequency tones, we know that the drug has approached the apex of the coiled tube. And that's what happened—we literally watched the guinea pigs lose their hearing in a cascade of frequencies, first as the high-frequency hearing diminished, then as the lower-frequency hearing was lost.

We succeeded in demonstrating for the first time that the parameters of hearing can be modulated in a controlled manner using an engineered, preprogrammed delivery device. We also established a margin of safety within which drugs can be effectively delivered without damaging sensitive hearing structures. The downside of the device is that any drug supply will eventually be depleted, but we are optimistic that by the time the device is ready for market, we'll be able to implant at least a year's worth of a highly concentrated drug.

As is true with all implantable devices, one of the key challenges we still face is how to power the device. We envision one small battery that's implanted and one slightly larger battery that's either on the surface of the skin behind the ear or tucked just underneath the ear. This larger battery would be easily rechargeable and replaceable and could, in turn, wirelessly recharge the embedded battery.

There are many hurdles to overcome in the development of this or any other electronically controlled implantable drug-delivery system. These obstacles run the gamut from microfluidic challenges to surgical and biological considerations. Once these hurdles have been cleared, implantable drug-delivery devices ought to see a healthy future. With electronics taking the bulk of the work away from them, patients can look forward to healthier, simpler, and most of all, more enjoyable lives. ❑

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COMPUTER REBORN//////////

BREATHES NEW LIFE INTO THE

BY PHILIP E. ROSS//PHOTOS

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A GANG OF VETERAN ENGINEERS HULK OF AN OLD MACHINE/////

BY MARK RICHARDS////////////

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MANY GOOD THINGS

from the good old days are gone—children playing outside, fruit that tastes better than it looks, luxurious air travel. But how could anyone get nostalgic about yesterday's big-iron computers, which were worse than today's handhelds by every measure?

"There's nothing like your first love," says Ed Thelen, a retired engineer who with 30-odd other people has restored a vintage IBM 1401 computer for the Computer History Museum, in Mountain View, Calif. "It's a mechanical machine: The tape machine has an air sensor, a little rubber diaphragm with contacts on it, and you can see it work. With these modern computers, it's just magic—they've got things a few nanometers long, and you'll never see them."

In the 1401's heyday, in the 1960s, some 9300 units were in use. Together with 6000-odd units of various successor models, by 1967 the 1400 line accounted for half of all the computers in the world. Companies used them mostly to sort things, notably for accounting, payroll, transaction analysis, and inventory control.

IBM

BACK TO THE FUTURE: An IBM 1401 system [left] filled a room. Its equivalent now fits in your hand. The CPU operator's panel [below] shows data lines linking registers, switches, and memory.

The machines have also had cultural resonance. The movie *Dr. Strangelove* (1964), a dark satire on nuclear war, showed a 1401 in one scene. The Icelandic composer Jóhann Jóhannsson wrote the orchestral work *IBM 1401: A User's Manual* (2006), which is available on iTunes.

The machine was a hit because it was simple and inexpensive. The 1401 processed numbers in decimal rather than binary form and accepted numbers of varying digit spans. Companies leased it for US $6500 a month, equivalent to $45 000 today—a bargain for an all-transistor design with stored programs. Such features had been offered only in huge systems costing about six times as much.

The museum got an even better bargain in 2003, when five enthusiasts gave it an old 1401 they'd bought on the

MY MIND IS GOING, DAVE.
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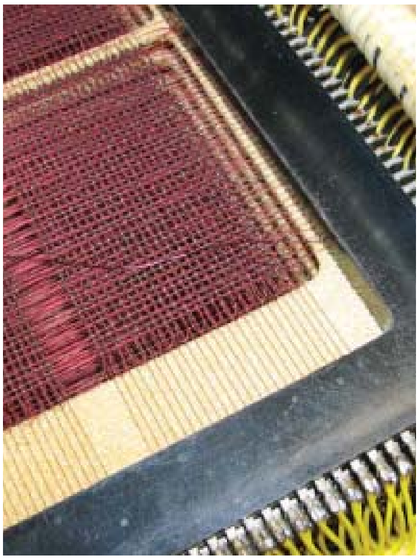
Robert Garner [left], head of the team that restored the IBM 1401, didn't know what a 1401 was when he volunteered to start the project in 2003. He stands next to the CPU, his arm on two tilted-out gates whose cards manage memory and storage. Ron Williams, in charge of the processor restoration, leans on the frame that holds the logic cards. A magnetic core memory [below], the rapid-access medium of the day, stored ones and zeroes in the magnetic fields of little "doughnuts" strung on crossing wires. PHOTO BELOW: JUDITH HAEMMERLE



SEARCHING MEMORY.... SEARCHING...
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IBM's 729 magnetic tape drive [left] was one of those iconic things that gave 1960s-era computer systems their look, sound, and feel. Its tape had seven tracks and spun faster than the eye could follow. Joe Preston [left] and Glenn Lea were customer engineers for IBM when the drive was still cutting-edge technology.

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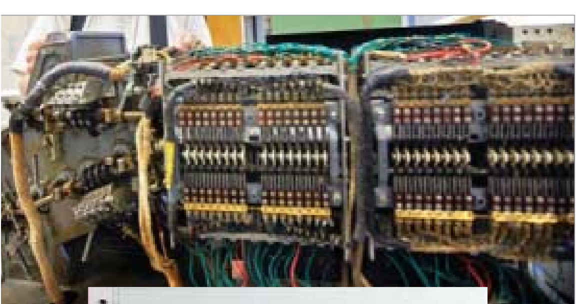
German eBay site for a mere €18 000, then about $21 000.

In part, the low price reflects the water damage that occurred during storage in Hamburg, damage the rehabbers took some 10 000 man-hours to repair, typically with old parts. Sometimes it helped that the rehabbers themselves were old: Bob Erickson was servicing IBM equipment for the U.S. Navy in 1943. The selling price also reflects the old-tech fervor of the seller, a German engineer who'd bought the machine for his own use in 1972, when IBM stopped supporting the model, and couldn't bear to scrap it when its working life was done. And of course, there's the effect of Moore's Law: The 1401 system, all 4 tons of it, has about one-millionth the computing power of your $600 desktop PC.

For hard jobs, though, the museum (http://www.computerhistory.org) can always throw more iron into the pot. It now has another 1401, purchased in Connecticut. Together the machines gulp 20 kilowatts, as much as four electric stoves with all their burners glowing red. ❏

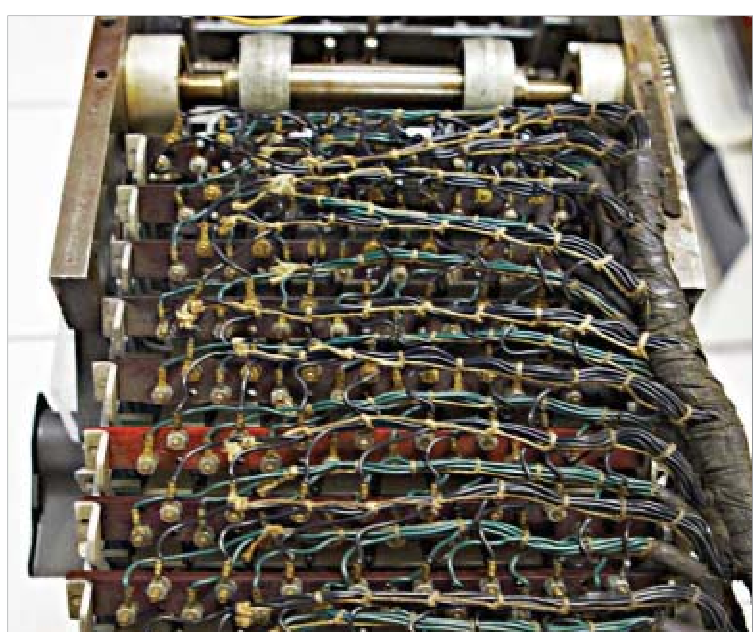


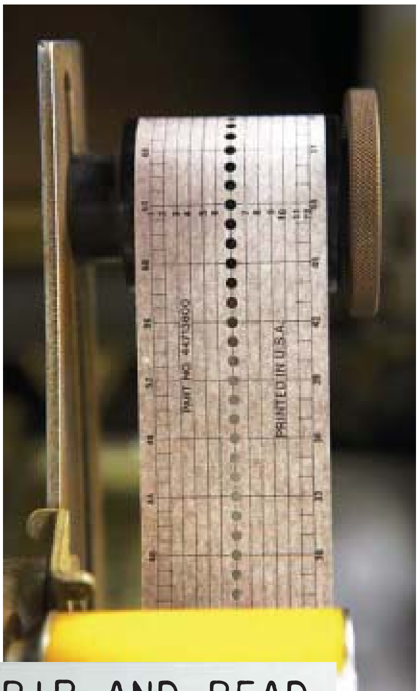
CARD COUNTING
****

The IBM 026 keypunch [top photo above], a design dating back to the 1940s, entered numbers and letters into a data card. The IBM 077 collator—whose guts are on display directly above—mixed and matched cards from many sources into a single deck.

WHEELS WITHIN WHEELS
****

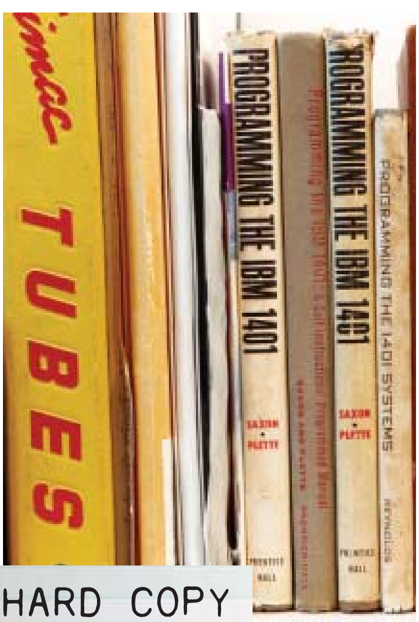
IBM's 513 reproducing punch, shown with rehabbers Frank King [left] and Robert Erickson, used 80 magnetic actuators [bottom]; the cards were moved by a gear transmission [detail, above].





RIP AND READ
****

IBM's 1403 printer [right] printed faster and more clearly than previous devices. It used a chain of letters moving horizontally, so that each hammer would hit a selected letter just as it passed by. That way, any timing error would affect only the spaces between the letters. In older systems, in which character-carrying cylinders rotated vertically, such an error would instead cause the machine to print a letter above or below the line, making the text hard to read. The tape [above] controlled the 1403's movement. Don Luke [left] and Frank King restored it.



HARD COPY
****

Nonvirtual tools [far right], paper manuals [above], and handwritten memos [near right] show young museum visitors what work was like back in the day.

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ON
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Organic (But Not Green)

Forget biofuels—only inorganic energy sources can provide prosperity for all and forever

By DEEPAK DIVAN & FRANK KREIKEBAUM

Sustainable, green, renewable, organic—the words come up so often in energy and climate debates that they tend to sound as if they mean the same thing. But of course they don't. Nuclear reactors emit no carbon and are therefore in a sense green, but uranium is nonrenewable; hydropower is green and renewable but may not always be sustainable, because the ecological consequences can be bad and reservoirs are not limitless; coal is organic, but its carbon emissions make it the very opposite of green. All that is obvious enough. But even so, it may be jarring to hear—as we have found and will describe—that organic biofuels can't possibly fuel a growing world economy in a sustainable manner, whereas, in principle, inorganic fuels could.

That inorganic might beat organic contradicts fashionable prejudice, which like all fashion changes with the season. Take the case of the United States: First came the enthusiasm for corn ethanol, its extravagant subsidization, and a farm-industrial miniboom. Then, when corn's limits started to become better known and its costs more glaringly obvious, we started to hear about the promise of switchgrass, a native species of the North American prairie that promises high energy-conversion efficiencies. President George W. Bush first mentioned it in a 2006 speech to the nation. Before long, Al Gore was chiming in too, promising that with adequate government support for research, grass-based fuels could free

PHOTO: DAN SAELINGER; STYLING: LAUREN SHIELDS

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us from the dual specters of energy shortage and runaway climate change.

In Germany rapeseed has been all the rage; in India, jatropha; and in Brazil, sugarcane ethanol. Yet the plain fact is that nobody really knows when or whether organic fuels will be competitive. Engineering breakthroughs, by their nature, are unpredictable—that's what makes them exciting. So to evaluate whether organic fuels could ever be in a position to power the world, we looked at them purely in terms of physical resource availability, assuming that the costs would eventually become competitive. We asked how much land and water would be needed to make the quantities of biofuel that a prosperous world would need. We also asked whether there were other sources of fuel and energy that might put less strain on resources while adding less greenhouse gas to the atmosphere.

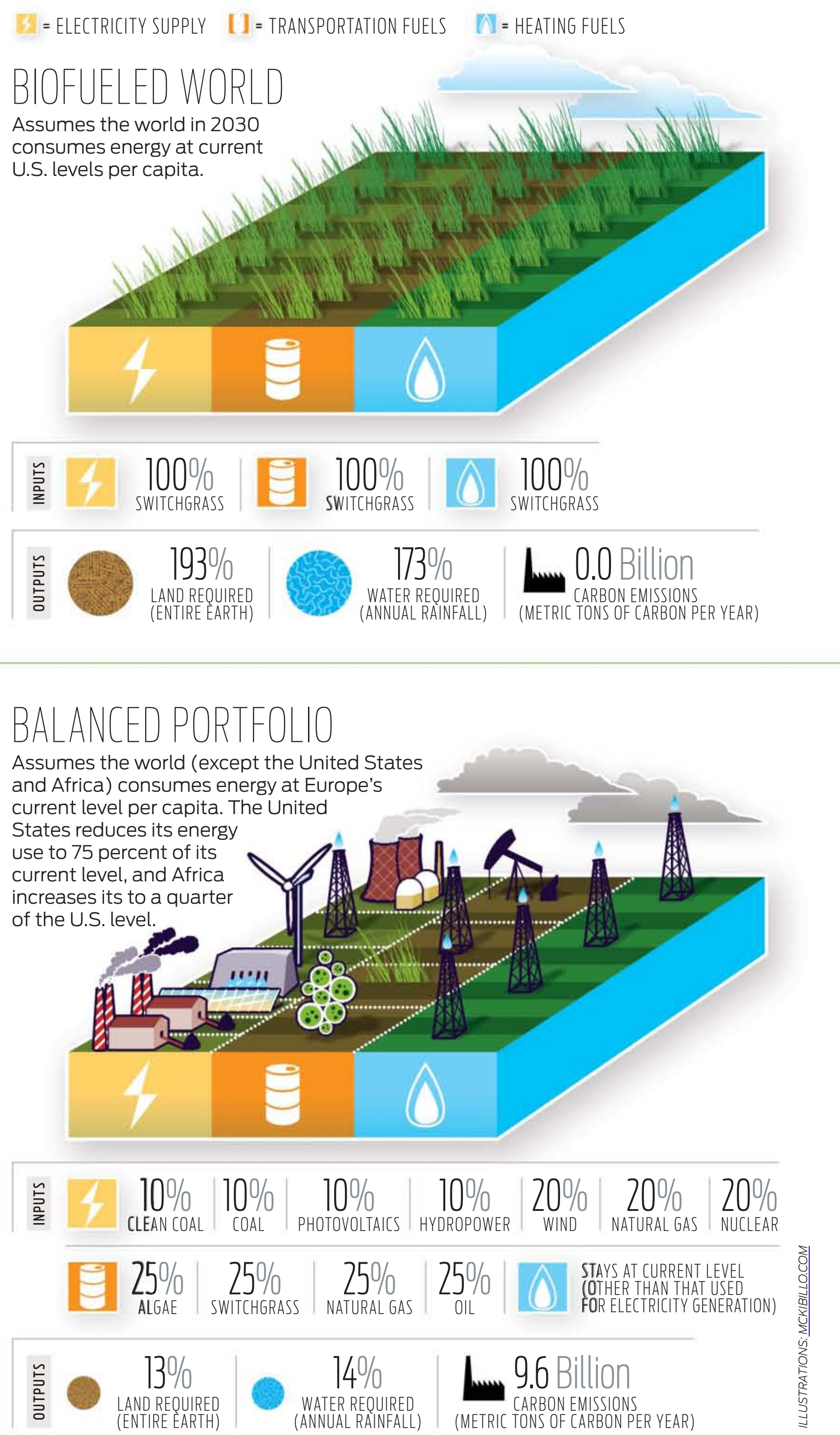
To our own surprise, the model we constructed showed that there is simply not enough land and water to support a prosperous biofueled world. At the same time, it suggested that inorganic sources, such as photovoltaic cells, can in principle do the job.

OUR SIMPLE MODEL, developed at the school of electrical and computer engineering at Georgia Tech, is designed to evaluate alternative energy scenarios. It simulates the consumption of energy, land, water, and carbon both globally and on regional scales; it projects emissions of carbon and waste heat; and it takes all obvious interdependencies into account. It assumes that electricity and water can move throughout the world without loss, that all land and freshwater are available for human use, and that in 20 to 25 years all the countries of the world will have access to sufficient resources to live as well as the United States does today.

The last point deserves some emphasis. Many futuristic energy models, including some much more complicated and sophisticated than ours, constrain future economic development in the name of sustainability. On both moral grounds and as a matter of practical politics, we reject such constraints. There is no justifying a regime that would limit a large fraction of the world's population to a much lower level of prosperity than North Americans, Europeans, and Japanese now enjoy, nor would Brazilians, Chinese, or Indians agree to

Switchgrass *vs.* Photovoltaics

There isn't enough water or land to sustain a prosperous world powered entirely by biofuels, but a similar world



ILLUSTRATIONS: MCKIBILLO.COM

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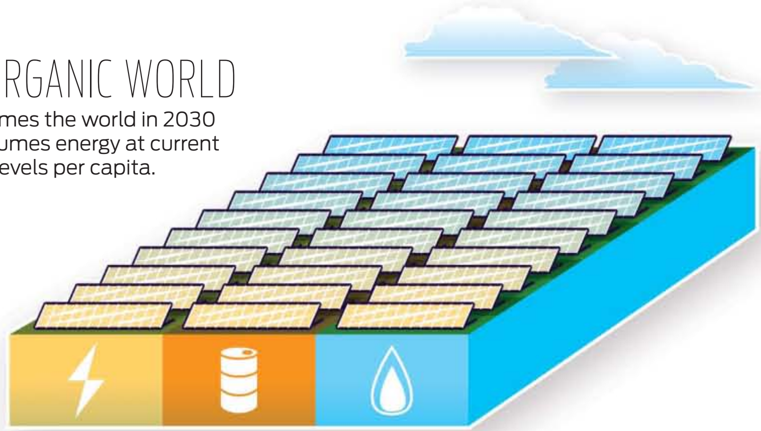
powered by solar energy is at least theoretically possible. Realistically, the future will have elements of both.

INORGANIC WORLD

Assumes the world in 2030 consumes energy at current U.S. levels per capita.



INPUTS

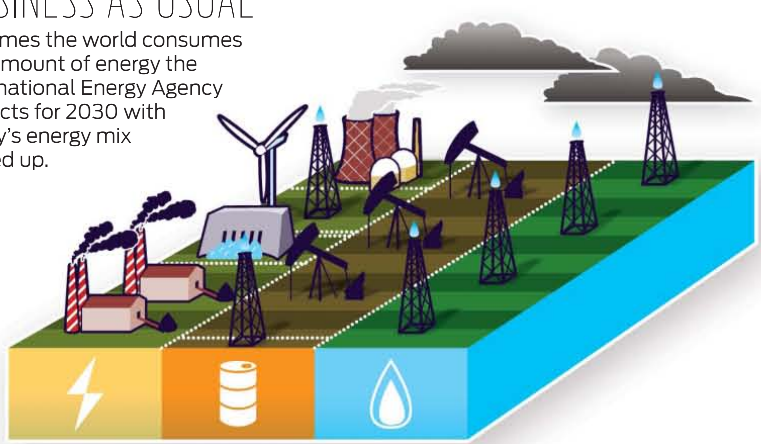
100% PHOTOVOLTAICS | 100% PHOTOVOLTAICS | 100% PHOTOVOLTAICS

OUTPUTS

6% LAND REQUIRED (ENTIRE EARTH) | 12% WATER REQUIRED (ANNUAL RAINFALL) | 0.0 Billion CARBON EMISSIONS (METRIC TONS OF CARBON PER YEAR)

BUSINESS AS USUAL

Assumes the world consumes the amount of energy the International Energy Agency projects for 2030 with today's energy mix scaled up.



INPUTS

0% CLEAN COAL | 45% COAL | 0% PHOTOVOLTAICS | 15% HYDROPOWER | 1% WIND | 24% NATURAL GAS | 15% NUCLEAR

0% ALGAE | 0% SWITCHGRASS | 5% NATURAL GAS | 95% OIL

STAYS AT CURRENT LEVEL (OTHER THAN THAT USED FOR ELECTRICITY GENERATION)

OUTPUTS

2% LAND REQUIRED (ENTIRE EARTH) | 5% WATER REQUIRED (ANNUAL RAINFALL) | 17.0 Billion CARBON EMISSIONS (METRIC TONS OF CARBON PER YEAR)

such an arrangement. Therefore, in evaluating the demands that the consumption of energy in whatever form would place on the earth, the water supply, and the atmosphere, we assumed that nobody in the world would be denied the aspiration of reaching the current U.S. level of consumption and prosperity just because available resources have been consumed by the wealthier and more developed nations. Some may quibble that our growth projections are ambitious, and so they are; our key assertion is that sufficient energy must be available to enable economic growth if the average world citizen is to live at current U.S. levels by 2030 or 2050.

Today most of the world's agricultural output is consumed by people and their livestock, and in the prosperous countries the vast majority of the grain goes to the livestock. But for simplicity's sake we have assumed that all the food in the world would come to our tables as grain or meat and that the output would be split into just two crops, summer corn and winter wheat. Further, we assumed that land taken from those crops to produce biofuels instead will all be used to produce just one crop, namely switchgrass, or to make room for one renewable but inorganic resource, namely photovoltaic (PV) electricity. In this way, we put the organic and inorganic futures into the starkest contrast.

Those choices, though obviously not realistic, struck us as reasonably conservative. Switchgrass seemed a fair compromise among biofuels; it has a good shot at near-term economic viability because it can provide more net energy for a given amount of carbon emissions than corn ethanol. In the longer run there may be more promise in futuristic biofuels made from sources such as bioengineered algae, but to become competitive they will require many scientific and technological advances.

Photovoltaic electricity, like switchgrass, presents challenges but also seems likely to achieve economic competitiveness in the foreseeable future without requiring extraordinary scientific breakthroughs. Wind is the more successful renewable energy resource today because of its economics, but in the medium term, solar energy may have greater potential, because there is just so much of it. Enough solar energy reaches Earth's surface in 90 minutes to supply all the world's current energy needs for a year.

Yes, You *Can* Try This at Home

An interactive version of the model described here is available at http://spectrum.ieee.org/energy/renewables/energy-calculator. Enter a chosen level of prosperity for each area of the world, specify how electricity will be generated and vehicles moved, and voilà: You'll see how much land and water is used and how much carbon is emitted.

THE RESULTS of our exercise are as follows. Both the biofuel and solar scenarios are carbon neutral by definition—solar for obvious reasons, biomass because carbon emitted in combustion is reabsorbed when plants regrow. (Admittedly, biofuels are carbon neutral only if crops are planted in existing tilled fields and the emissions connected with fertilizer use, irrigation, and transportation are left out of account. Analogous qualifications hold for PV.)

A sustainable biofueled world, it turns out, would require 32 times as much land and 14 times as much water as a solar world to meet a prosperous world's food and energy needs. In fact, a world enjoying current U.S. levels of prosperity, fueled by switchgrass, would require almost twice as much land and freshwater as are actually available on Earth [see illustration, "Switchgrass vs. Photovoltaics"].

Biofuels provide around 6.5 megawatt-hours per day per square kilometer. That's roughly enough to power 60 homes or carry 135 conventional cars 50 kilometers (about 30 miles). A photovoltaic system covering the same square kilometer, with a typical commercially available system efficiency of 15.5 percent, could power 12 000 homes or 60 000 electric vehicles. In this solar scenario, cars powered by the internal combustion engine are replaced with electric vehicles that are three times as efficient—a direct result of losses in the thermal cycle of the internal combustion engine.

We expect continued improvements in the energy yield from biofuel feedstocks. For example, if the yield from switchgrass improves by 300 percent, as analysts expect it to do over the next 40 years, we'd need to commandeer "only" 68 percent of the land and 66 percent of the freshwater in the *Continued on page 52*

HENRIK JONSSON/ISTOCKPHOTO

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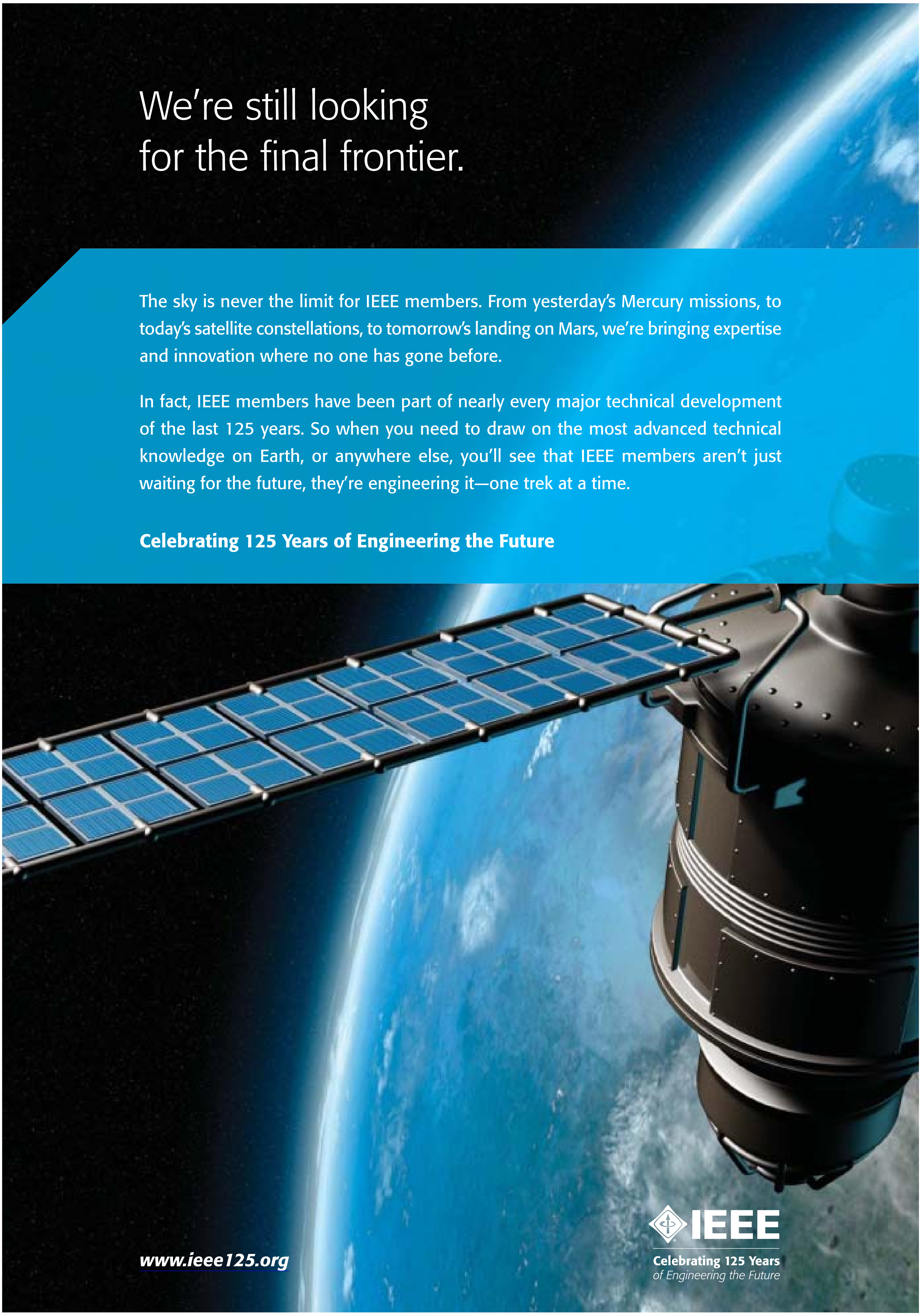
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Organic (But Not Green)

Continued from page 50

world. Of course, that would ravage biodiversity, leaving us open to horrible consequences should some blight kill off the crop we were depending on. Most important, future increases in energy consumption would be severely limited.

YOU CAN DESIGN your own 2030 scenario by taking our model and setting the parameters yourself, to evaluate resource requirements in terms of objectives, and sustainability ideals in terms of realities [see box, "Yes, You *Can* Try This at Home"]. For example, if you feel you really don't know enough to predict what technologies will win out in the long run, you might want to assume that all major energy sources will still make substantial contributions, as will some new ones, such as algal biofuels. Rather than assume the whole world will be consuming energy in 2030 at the rather extravagant U.S. level, you might want to set consumption at European levels.

In a "balanced portfolio" scenario, for example, natural gas, nuclear, and wind might contribute 20 percent each to the world's electrical energy in 2030, with 10 percent each coming from hydropower, solar power, clean coal, and traditional coal; algal biofuels, switchgrass, natural gas, and oil would each account for a quarter of vehicular fuels.

Alternatively, in a "business as usual" scenario, the world consumes energy in 2030 at the level predicted by the International Energy Agency, with all energy produced just as it is today. The results of these experiments? There would be enough land and freshwater to make either scenario imaginable, but carbon emissions in 2030 would be significantly higher than today's 7.5 billion metric tons—and a far cry from the reductions world leaders hope to adopt this December at the United Nations Climate Change Conference in Copenhagen.

LEGISLATIVE MANDATES around the world are encouraging increased use of PV, wind, and biofuels. For example, national tax credits, production mandates, and import tariffs are promoting biofuel production in the United States. In Germany, prosolar policies have prompted companies to boost global photovoltaics production capacity. But even a simple resource study like ours points to the need to carefully consider how easily the subsidized energy solutions can be scaled up and to the need to identify any unintended consequences. The failure to consider the scalability of a program can easily put a country on the wrong track. What's worse, it can create vested interests that will make a particular course all the harder to correct once the error becomes plain to all.

Energy policy involves a complex interplay of science, technology, culture, history, policy, and economics. Even the experts are confused. We believe we've made life easier for all people interested in energy policy by helping them measure things, so that they can rank policy options in terms of their scalability and long-term sustainability. And unless something changes in a very big way, the ranking will be very clear indeed: Our work shows that known biofuel technologies must become 100 to 200 times as efficient as they are now before they can begin to compete with solar power and other inorganic sources of energy on a global resource basis. ❏

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THE HONG KONG POLYTECHNIC UNIVERSITY
香港理工大學

DEPARTMENT OF COMPUTING

The Department invites applications for Professors in Database and Information Systems / AI and Knowledge Engineering / Computer System and Theory (Algorithms, OS, Computer Language, etc.). The appointees will be required to provide leadership in all aspects of academic activities, develop established or new research areas in the Department, take responsibility for the development of teaching programmes, and strengthen the international network of the Department and the University. Applicants should have a PhD degree in Computer Science and be conversant in other related disciplines, outstanding abilities with good administrative experience as an academic leader, and excellent track record in research and high quality publications. Please visit the website at http://www.comp.polyu.edu.hk for more information about the Department. Salary offered will be commensurate with qualifications and experience. Initial appointments will be made on a fixed-term gratuity-bearing contract. Re-engagement thereafter is subject to mutual agreement. Remuneration package will be highly competitive. Applicants should state their current and expected salary in the application. Please submit your application via email to hrstaff@polyu.edu.hk. Application forms can be downloaded from http://www.polyu.edu.hk/hro/job.htm. Deadline for application is 17 February 2010. Details of the University's Personal Information Collection Statement for recruitment can be found at http://www.polyu.edu.hk/hro/jobpics.htm.

UNIVERSITY OF ALBERTA
EDMONTON, ALBERTA, CANADA

www.careers.ualberta.ca

Faculty Positions, All Ranks Electrical and Computer Engineering

The Department of Electrical and Computer Engineering at the University of Alberta invites applications for several tenure track and tenured faculty positions at the Assistant, Associate and Full Professor levels. Exceptional candidates are being sought in all areas of Electrical Engineering, Computer Engineering, and Engineering Physics with emphasis on the overall excellence, originality and promise of the candidate's work rather than the specific area of specialization. Successful candidates will be expected to develop a significant independent research program with external funding, supervise graduate students in their field of interest, and teach postgraduate and undergraduate courses in electrical and computer engineering.

Candidates must have earned (or expect shortly) a PhD in electrical and computer engineering or a closely related area; have a solid publication record; show ability or potential to establish an independent research program; and demonstrate a commitment to excel in both research and teaching. Postdoctoral and/or industrial experience will be considered an asset. Successful candidates will also be required in due course to become licensed professional engineers in the Province of Alberta.

Founded in 1908, the University of Alberta is one of Canada's foremost research-intensive universities. The campus is situated on the south bank of the North Saskatchewan River, with quick and convenient access to the city centre. The greater Edmonton area has a population of over a million people and offers a diverse array of cultural and sporting activities year round. The Department of Electrical and Computer Engineering is undergoing a major expansion and is committed to securing a position among the leading research schools in North America. With a present complement of 61 faculty members, research in the Department is vigorous and covers all major areas of Electrical and Computer Engineering and Engineering Physics. Our graduate program attracts outstanding students from the best schools worldwide and presently has an enrollment of approximately 400 Masters and PhD students. The undergraduate programs in Electrical Engineering (which includes options in biomedical engineering and nanoengineering), Computer Engineering (which includes options in Software Engineering and nanoscale systems design), and Engineering Physics (with an option in Nanoengineering), enroll over 600 students. Research and teaching needs are served by two new buildings with a total area of 340,000 square feet. Facilities include a state of the art machine shop, and a unique world-class nano and microfabrication facility. Located nearby, the National Institute for Nanotechnology (NINT) offers unique opportunities for collaboration with faculty, industry and government. The undergraduate and graduate laboratories are generously equipped with state of the art equipment and excellent computing facilities are available. Extensive funding opportunities are available through a variety of national and provincial sources. Further information about the Department can be found at www.ece.ualberta.ca.

Applicants are invited to submit their curriculum vitae including employment history, a statement outlining research and teaching interests, a brief description of major contributions, reprints of at least two representative research papers, and the names of at least three referees. Applications can be sent electronically in PDF format only. The review of applications will begin on November 30, 2009; however, the competition will remain open until all positions are filled.

Dr. H. J. Marquez, Chair
Department of Electrical and Computer Engineering
University of Alberta
Edmonton, Alberta T6G 2V4 Canada
Email: marquez@ece.ualberta.ca

All qualified candidates are encouraged to apply; however, Canadians and permanent residents will be given priority. If suitable Canadian citizens and permanent residents cannot be found, other individuals will be considered. The University of Alberta hires on the basis of merit. We are committed to the principle of equity in employment. We welcome diversity and encourage applications from all qualified women and men, including persons with disabilities, members of visible minorities, and Aboriginal persons.

Canada's Top 100 Employers 2009

ÉCOLE POLYTECHNIQUE FÉDÉRALE DE LAUSANNE

Faculty Positions in Circuits and Systems for Telecommunications

at the Ecole Polytechnique Fédérale de Lausanne (EPFL)

The Institute of Electrical Engineering at EPFL invites applications for a **tenure track assistant professor** position in the area of **Circuits and Systems for Telecommunications.**

Areas of interest include, but are not limited to, circuits, systems and networks for wireless and wired communication, high-frequency and modulation systems, baseband processing, computer network components, data routing, signaling and coupling to transmission media like fiber optics and antennas. The candidate needs to show excellent capabilities in realizing physical embodiments of telecommunications circuits and systems in classic and non-conventional application domains.

The successful candidate is expected to initiate independent, creative research programs and actively participate in undergraduate and graduate teaching.

Significant start-up resources and state-of-the-art research infrastructure will be available. Salaries and benefits are internationally competitive.

Applications should include a cover letter with a statement of motivation, curriculum vitae, list of publications and patents, concise statement of research and teaching interests, and the names and addresses of 6 references. Applications must be uploaded in PDF format to the web site **http://tc-search09.epfl.ch.**

Candidate evaluation will begin on **1 December 2009.**

Enquiries may be addressed to:
Prof. Juan R. Mosig
Search Committee Chair
EPFL, Station 11
CH-1015 Lausanne, Switzerland
E-mail: **telecom.search@epfl.ch**

For additional information on EPFL, please consult the web sites **http://www.epfl.ch, http://sti.epfl.ch** and **http://iel.epfl.ch.**

EPFL aims to increase the presence of women amongst its faculty, and qualified female candidates are strongly encouraged to apply.

ETH

Eidgenössische Technische Hochschule Zürich
Swiss Federal Institute of Technology Zurich

Professorship in Mathematical Methods in Information and Communication Technology

The Department of Information Technology and Electrical Engineering (www.ee.ethz.ch/en) at ETH Zurich invites applications for the above-mentioned professorship. The successful candidate is expected to develop a strong and visible research program in the area of Information and Communication Technology. We are looking for applicants with a strong mathematical background working in any of the following research areas: signal and image processing, communications, control, information theory, computer architecture, and networking.

Candidates should have a Ph.D. degree and an excellent record of accomplishments in Information and Communication Technology. In addition, commitment to teaching and the ability to lead a research group are expected. The successful candidate will be expected to teach undergraduate level courses (German or English) and graduate level courses (English).

The position can be filled at either assistant professor (tenure track), associate or full professor level, depending on the scientific track record of the applicant.

Assistant professorships have been established to promote the careers of younger scientists. The initial appointment is for four years with the possibility of renewal for an additional two-year period and promotion to a permanent position.

Please submit your application including a curriculum vitae, a list of publications, and statements on future research and teaching activities to the **President of ETH Zurich, Prof. Dr. Ralph Eichler, ETH Zurich, Raemistrasse 101, 8092 Zurich, Switzerland, no later than January 31, 2010.** With a view toward increasing the number of female professors, ETH Zurich specifically encourages qualified female candidates to apply.

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THE UNIVERSITY OF UTAH

The Department of Electrical and Computer Engineering, University of Utah, Salt Lake City, seeks applications to fill at least two tenure-track positions at the assistant, associate or full professor level for an interdisciplinary research cluster in ***Micro and Nanosystem Integration and Packaging***.

We are particularly interested in candidates with background in electronic micro/nano-system integration and packaging, biocompatible materials and packaging, solid state devices, reliability, testing, and micro/nano system modeling and simulation. Information on department research activities and curricula may be found on the web at **www.ece.utah.edu**. The web site also has information on two more positions available in the department. Information on the College of Engineering can be found at **www.coe.utah.edu**. Successful candidates will conduct research with tenure track appointments in the Department of Electrical and Computer Engineering, but may also be appointed in other departments such as Materials Science, Bioengineering or Mechanical Engineering. Suitable candidates may be considered for joint appointments with the College of Science or the Medical School at the University of Utah.

These positions are part of the Utah Science, Technology and Research Initiative (USTAR), which was funded by the Utah State Legislature to attract focused teams of outstanding researchers who have the potential to help build major research programs and create new technology that can ultimately lead to commercial products and/or new industries for Utah. The USTAR initiative is also supporting a new interdisciplinary building which will house a new nanofabrication laboratory and characterization facilities that will cater to solid state devices, MEMS, sensor and packaging research and development, as well as the handling of biomedical samples. The building will facilitate communication for researchers such as the ones hired under this solicitation, from engineering, sciences and the medical school, as well as offering lab access for selected industrial stake holders. Information on the USTAR initiative can be found under **www.ustar.utah.gov**. Candidates for this initiative should have a demonstrated track record of successful, funded projects and an interest or track record in technology commercialization, entrepreneurial or industrial experience.

The positions are also associated with and partially supported by the ***Fraunhofer Institute for Reliability and Microintegration IZM***, and leverage a strong collaborative and international research program with a Fraunhofer IZM branch laboratory in Utah. Fraunhofer support includes in-house access to Fraunhofer infrastructure, know-how, and resources. Selected positions may be associated with joint Fraunhofer appointments, possibly at a center director's or co-director's level.

Résumés with names, contact information for at least three references, and statements for research and teaching goals should be sent to Ms. Debbie Sparks, USTAR Faculty Search Committee, University of Utah, Electrical and Computer Engineering Department, 50 South Central Campus Drive, Room 3280, Salt Lake City, UT 84112-9206. Email applications are accepted at **dsparks@ece.utah.edu**. Applications will be reviewed starting September 1, 2009, and will be accepted until the positions are filled.

Faculty responsibilities include developing and maintaining an internationally recognized research program, effective classroom teaching at the undergraduate and graduate levels, and professional service. Applicants must hold a Ph.D. by the time of appointment. The University of Utah values candidates who have experience working in settings with students from diverse backgrounds and possess a strong commitment to improving access to higher education for historically underrepresented students. The University is an AA/EO employer, encourages applications from women and minorities, and provides reasonable accommodations for known disabilities of applicants and employees.

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Carnegie Mellon Qatar
School of Computer Science
Qatar Foundation

Computer Science Faculty Positions

Carnegie Mellon University in Qatar invites applications for teaching-track positions at all levels in the field of Computer Science. These career-oriented renewable appointments involve teaching international undergraduate students, and maintaining a significant research program. Candidates must have a Ph.D. in Computer Science or related field, substantial exposure to Western-style education, outstanding teaching record and excellent research accomplishments or potential.

Specifically, we are seeking candidates with expertise in databases, data mining, web technology and human-computer interaction. Truly exceptional candidates in other areas also will be considered.

The position offers a competitive salary, foreign service premium, research seed grant, excellent international health coverage and allowances for housing, transportation, dependent schooling and travel.

Carnegie Mellon is internationally recognized as a leader in research and higher education. In 2004, the university established itself in Education City, a state-of-the-art campus that is home to six top universities. Collaboration opportunities with internationally-known researchers and world-class businesses are abundant.

For further information or to apply, visit
http://www.qatar.cmu.edu/cs/positions/

The Petroleum Institute
Abu Dhabi, United Arab Emirates

Institution: The Petroleum Institute (PI) in Abu Dhabi, United Arab Emirates was created in 2001 with the goal of establishing itself as a recognized institution in engineering education and research in areas of significance to the oil and gas and the broader energy industries. The PI's sponsors include the Abu Dhabi National Oil Company and four major other international oil companies, namely BP, Shell, Jodco, and Total. The Institute is affiliated with and has collaborative programs in place with the Colorado School of Mines, the University of Maryland at College Park, The University of Minnesota, and Leoben and Linz Universities (Austria). For more information, please refer to the PI website: www.pi.ac.ae.

FACULTY POSITIONS
- ELECTRICAL ENGINEERING

The Electrical Engineering Department at the PI is seeking applications for the following positions:

Chaired Professor, Distinguished Professor
Professor, Associate Professor, Assistant Professor
Senior Research Associate, Research Associate

Applicants with research interests and experience in one or more of the following areas: instrumentation and measurements, smart sensors technology, condition monitoring, power quality, power systems, and with interest in applications in the Oil/Gas industry are especially encouraged to apply.

Program faculty will be expected to teach undergraduate and graduate courses, develop an active research program, and to engage in professional and institutional service activities. Opportunities to interact with PI industrial stakeholders and other local industries will be a key feature in the development of a research program.

Interested candidates should submit all materials online:

www.pi.ac.ae/jobs

Review of applications will begin immediately
and will continue until successful candidates are selected

Only short-listed applicants will be notified.

ieee spectrum classifieds

The University of Minnesota Twin Cities: invites applications for faculty positions in Electrical and Computer Engineering at all ranks in the core areas of the department (Computer Engineering, Fields/Photonics, Microelectronics, Signals/Systems/Communications, and Energy/Power Electronics) with expertise in bio-, energy-, and nano-related strategic areas. Women and other underrepresented groups, and those with interdisciplinary interests, are especially encouraged to apply. An earned doctorate in a discipline commensurate with the instructional needs of an ECE department is required. Rank and salary will be commensurate with qualifications and experience. Positions are open until filled, but for full consideration, apply by December 31, 2009. See http://www.ece.umn.edu/ECEJOBS.html for application requirements. The University of Minnesota is an equal opportunity employer and educator.

EPFL
ÉCOLE POLYTECHNIQUE FÉDÉRALE DE LAUSANNE

Faculty Positions in Mechanical Engineering at the Ecole polytechnique fédérale de Lausanne (EPFL)

The Institute of Mechanical Engineering within the School of Engineering at EPFL in Lausanne, Switzerland, is seeking outstanding **tenure-track assistant professors** in the broad field of mechanical engineering. Exceptionally well-qualified candidates may be considered at a more senior level. In particular, applicants with interest and demonstrated innovative research in the following areas are encouraged to apply:

- **Energy systems:** all aspects of sustainable and renewable energy systems including fuel cells, biofuel systems and turbomachinery.
- **Theoretical and computational mechanics** with emphasis on solid mechanics including soft matter and structural dynamics.
- **Dynamics and control,** in particular nonlinear dynamical systems, control and optimization of dynamical systems, with possible application to mechatronic and robotic systems.

The successful applicants are expected to develop an independent and internationally recognized research program and collaborate with other EPFL research groups as well as Swiss and international academic institutions. Besides providing leadership in research, the new professors will be required to teach core courses in their discipline at both the undergraduate and graduate levels. EPFL offers internationally competitive salaries, start-up resources and benefits. The Institute of Mechanical Engineering has outstanding experimental and computational facilities.

Interested individuals should include a résumé with a list of publications, a concise statement of research and teaching interests, and the names and addresses (including e-mail) of at least five referees. Applications should be uploaded to **http://igm-search09.epfl.ch.** The deadline for applications is **18 January 2010.**

Enquiries may be addressed to:
Prof. John Botsis
Search Committee Chairman
IGM-STI- EPFL, Station 9
CH-1015 Lausanne, Switzerland
E-mail: hiring.igm@epfl.ch

For additional information on EPFL, please consult the web sites: **http://www.epfl.ch, http://sti.epfl.ch** and **http://igm.epfl.ch**

EPFL aims to increase the presence of women amongst its faculty, and qualified female candidates are strongly encouraged to apply.

UCL Université catholique de Louvain

FACULTY POSITIONS at the Université catholique de Louvain, Louvain la Neuve, Belgium

The Louvain School of Engineering and the Electrical Engineering Department invite applications for ***tenure track*** positions of ***Professors*** in the fields of

1. Electronic circuits and systems
2. Energy and power electronics

The successful candidates are expected to have a strong scientific record in relation to the position applied for. They will have to initiate and lead research programs in the respective fields, and to teach at graduate and undergraduate levels. They are expected to be leaders in their fields and to cooperate with other teams of the School and of the Department.

For position 1, research interests include but are not limited to biomedical circuits and systems, design of mixed (analog-digital) circuits and systems. Cooperation is expected with the communications, signal and image and mecatronics research teams.

For position 2, cooperation is expected with research teams in electrical energy, electronics and mecatronics.

More information about the teams can be found at **http://www.uclouvain.be/en-icteam.html** and **http://www.uclouvain.be/en-immc**.

The information about the elements to be sent for application can be obtained from the main page of the university website: **http://www.uclouvain.be/**.

The application deadline is around January 15, 2010.

Information can be obtained from Prof. L. Vandendorpe, Head EE Dpt, (**luc.vandendorpe@uclouvain.be**).

THE UNIVERSITY OF UTAH

The Department of Electrical and Computer Engineering, University of Utah, Salt Lake City, seeks applications to fill two tenure-track positions at the assistant professor level. Outstanding applicants with significant experience may also be considered at the associate or full professor level.

We are particularly interested in candidates with expertise in electromagnetics and communications. Information on department research activities and curricula may be found on the web at **www.ece.utah.edu**. The web site also has information on additional positions available for the Utah Science, Technology and Research Initiative. Faculty responsibilities include developing and maintaining an internationally recognized research program, effective classroom teaching at the undergraduate and graduate levels, and professional service.

Résumés with names and contact information for at least three references should be sent to Ms. Debbie Sparks, Faculty Search Committee, University of Utah, Electrical and Computer Engineering Department, 50 South Central Campus Drive, Room 3280, Salt Lake City, UT 84112-9206. Email applications are accepted at **dsparks@ece.utah.edu**. Applications will be reviewed starting September 1, 2009, and will be accepted until the positions are filled. Applicants must hold a Ph.D. by the time of appointment. The University of Utah values candidates who have experience working in settings with students from diverse backgrounds and possess a strong commitment to improving access to higher education for historically underrepresented students. The University is an AA/EO employer, encourages applications from women and minorities, and provides reasonable accommodations for known disabilities of applicants and employees.

Faculty Position in Microengineering for Energy
at the Ecole polytechnique fédérale de Lausanne (EPFL)

EPFL
ÉCOLE POLYTECHNIQUE FÉDÉRALE DE LAUSANNE

The Institute of Microengineering (IMT) within the School of Engineering at EPFL is seeking for its Neuchatel site, a tenure track assistant professor in the wider field of **«green» integration technologies,** in particular, for **micro/nano-engineering of energy systems.** Exceptionally qualified candidates may also be considered at a more senior level. We encourage applications from candidates with strong expertise in the area of micro-nano technology (MEMS/NEMS) or manufacturing of micro- and nano-systems and materials/components for energy generation and storage. The research program should be strongly linked to the fields of smart systems integration or energy management of complex systems.

The successful applicant is expected to establish an internationally-recognized research program aimed at technological development for sustainable development, in accordance with the general mission of IMT-EPFL at Neuchatel on «Green Manufacturing». In particular, the research program should enable the development of efficient, energy saving, industrial fabrication processes, such as additive fabrication process, allowing high flexibility and application versatility. It should lead to a new generation of sustainable, reusable, recyclable and environmentally-friendly devices and systems.

Applications are encouraged from candidates having strong scientific knowledge and industrial collaboration in the areas of, but not restricted to, ambient assisted living, watches, wearable devices, smart homes and building, smart textiles, as well as sensors network. EPFL has first-class research facilities in micro / nanofabrication, robotics, mechatronics and microscopy. The successful candidate will work within IMT and is expected to collaborate with other EPFL units as well as Swiss and international academic institutions and industry. He/she is expected to provide leadership in research and participate in undergraduate and graduate teaching. EPFL offers internationally competitive salaries, start-up resources and benefits.

Applications should include a cover letter with a statement of motivation, curriculum vitae, list of publications and patents, concise statement of research and teaching interests, and the names and addresses (including e-mail) of at least five references. Applications should be uploaded in PDF format to: **http://greentec-rec.epfl.ch**

The deadline for applications is **15 January 2010.**

Enquiries may be addressed to:

Prof. Juergen Brugger
E-mail: greentec-rec@epfl.ch

For additional information on EPFL, please consult the web sites: **http://www.epfl.ch, http://sti.epfl.ch, http://imt.epfl.ch**

EPFL aims to increase the presence of women amongst its faculty, and qualified female candidates are strongly encouraged to apply.

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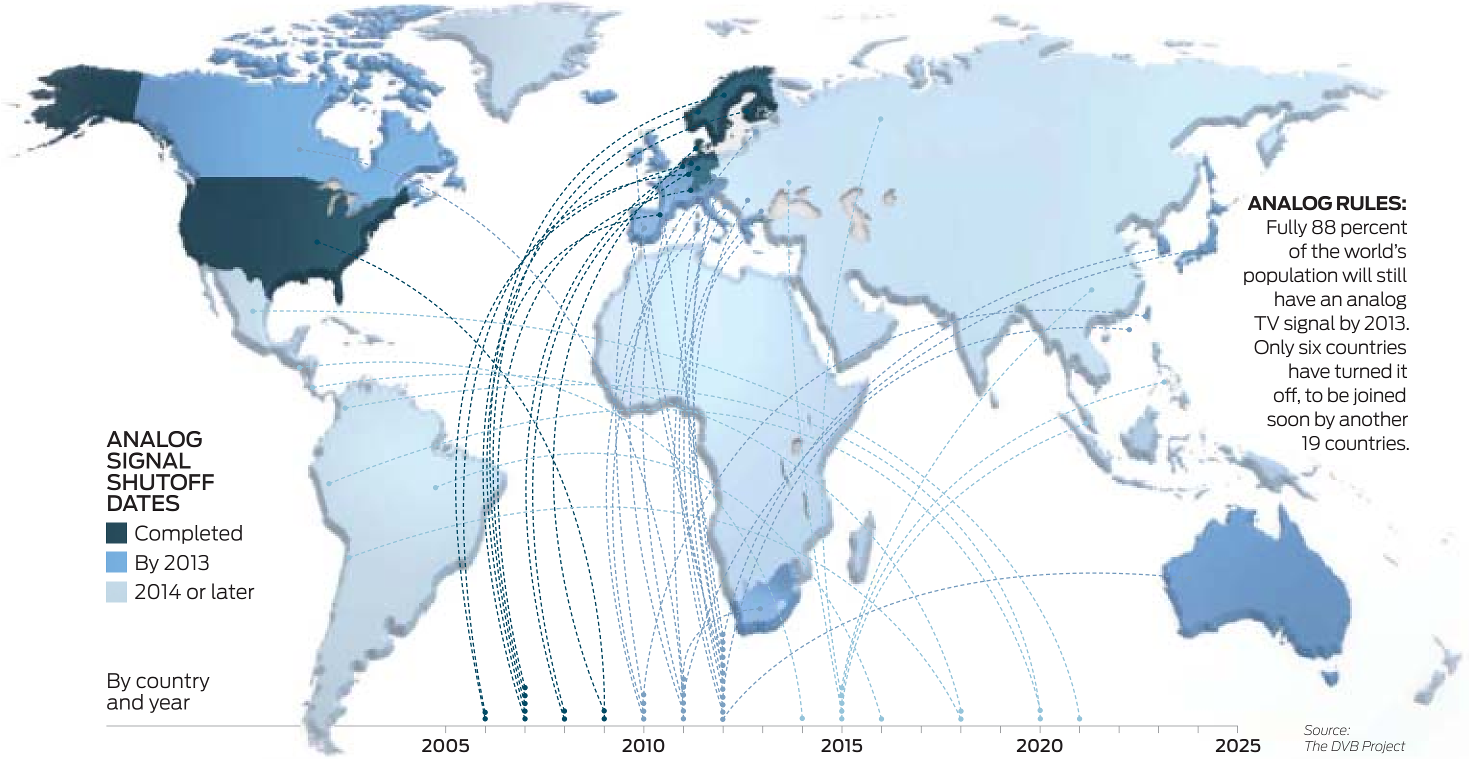


ANALOG RULES: Fully 88 percent of the world's population will still have an analog TV signal by 2013. Only six countries have turned it off, to be joined soon by another 19 countries.

Source: The DVB Project

Long Live Analog TV—on Cellphones

JUST AS countries around the world are replacing analog television with the digital kind, along come new technologies to receive the old-style signals on mobile phones.

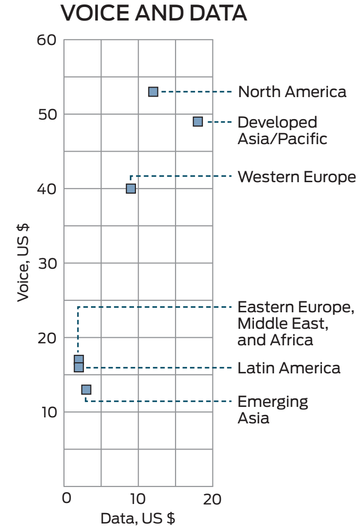
To make sure it hasn't invented an ultralow-power, single-chip buggy whip just as the equivalent of a Model T arrives on the market, Telegent Systems, a fabless manufacturer of complementary-metal-oxide semiconductors based in Sunnyvale, Calif., commissioned a worldwide study. Though based on only a few hundred survey responses per country, the results, from the analytical firm In-Stat, were encouraging.

In-Stat found that "the majority of the world's countries will broadcast analog TV, even after 2013." And those countries turn out to be the right ones—analog TV will still be around in the very places where consumers aren't spending much on cellular voice and data services. That's important, because mobile analog TV signals are already in the air and therefore can be received for free. Business models for digital TV services, such as 1seg in Japan and V Cast in the United States, involve expensive monthly subscriptions.

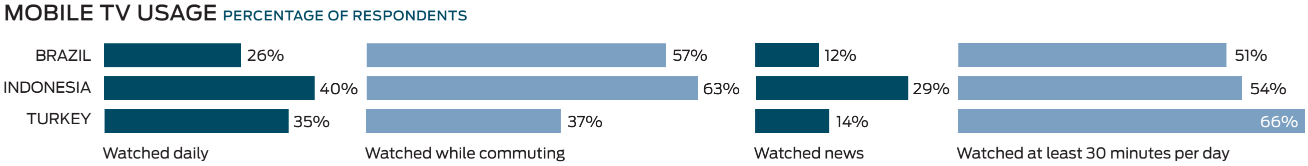
In-Stat divided the globe into six regions—three developed areas where people spend a lot on cellular services, and three developing ones where they do not. In the latter group, usage patterns are strikingly similar: News was the leading type of television program, more than half of the respondents watched at least 30 minutes of mobile television per day, and the most popular "circumstance of use" was mass-transit commuting.

—*Steven Cherry*

ANNUAL REVENUE PER USER FOR CELLULAR VOICE AND DATA



MOBILE TV USAGE PERCENTAGE OF RESPONDENTS



Sources: Telegent Systems, In-Stat

MAP: EMILY COOPER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