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EKSO BIONICS' **POWERED EXOSKELETON** LEADS A NEW CLASS OF ELECTROMECHANICAL GEAR THAT WILL PUT PARAPLEGICS BACK ON THEIR FEET

WALKING AGAIN

IT'S ONE OF **14** LIFE-ALTERING, GAME-CHANGING ADVANCES THAT MADE OUR 2012

TOP TECH SPECIAL REPORT

IEEE


Name
Dr. Laurel Watts
Job Title
Principal Software Engineer
Area of Expertise
Chemical Engineering
LabVIEW Helped Me
Control multiple instruments operating in harsh conditions
Latest Project
Engineer the ultimate storm chaser
NI LabVIEW
LabVIEW makes me better because the
INTEGRATION
with hardware is so seamless

volume 49 number 1 international

ieee spectrum 1.12

48

SPECIAL REPORT

TOP TECH 2012

COVER: GABRIELA HASBUN; RETOUCHING: STATIK DIGITAL

THIS PAGE: VIRGIN GALACTIC

volume 49 number 1 international

ieee spectrum 1.12

9

UPDATE

OPINION

DEPARTMENTS

SPECTRUM.IEEE.ORG AVAILABLE 1 JANUARY

Video: Walking Again

Tamara Mena has been confined to a car wheelchair since a car accident six years ago. Now Ekso legs have allowed her to get back on her feet. See Mena's Ekso system in action in an exclusive video: http://spectrum.ieee.org/ekso0112

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REDUCING ACCIDENTS WITH SMARTER CARS
Up to 90 percent of all car crashes caused by driver error could be eliminated with more-intelligent transportation systems, according to several IEEE members. Embedded systems, sensors, and microprocessors are just some of the technologies that could help. Learn what IEEE members are doing in this area.

NEW BOOK ON DEVELOPING LEADERS AND MANAGERS
Most books on effective leaders focus on CEOs, presidents, and others working at such lofty levels. But the important role of the manager is often overlooked. A new IEEE e-book on management says effective managing cannot exist without some level of leading.

IEEE AEROSPACE CONFERENCE
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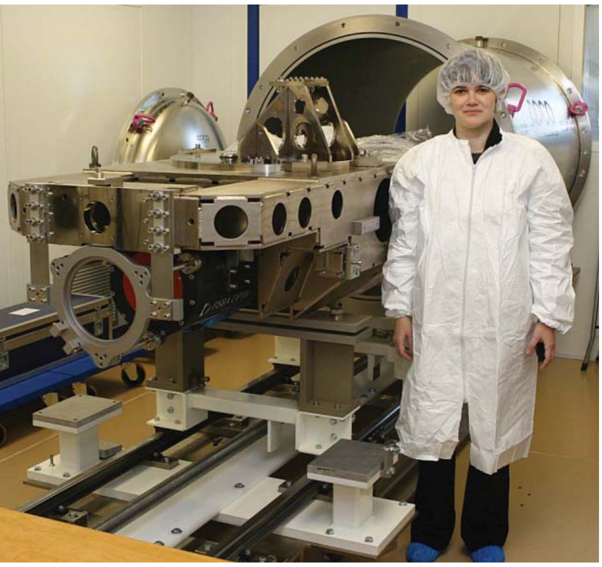
back story

A Planet Like Our Own

Breakthroughs in astronomy frequently begin with an unbelievably faint glimmer or murmur from space, plucked improbably from the sky by a telescope on a barren mountaintop, in a remote high desert, or in orbit around Earth.



And yet this past October, there was Associate Editor Rachel Courtland, riding through lush, sun-dappled roads on the outskirts of Geneva on her way to see one of the newest and most advanced tools for hunting planets beyond our solar system—the High Accuracy Radial velocity Planet Searcher–North.

HARPS-N, as it is known, will soon be shipped off to a remote location on La Palma, one of the Canary Islands. But when Courtland saw the instrument, it was being assembled in an old telescope building not far from the Geneva Observatory's main offices, in Sauverny, Switzerland.

She found an odd mix of quaint and high-tech. Some of the HARPS-N's key components were housed near displays of antique brass scopes not much different from the ones used to discover Neptune. To get into the clean room where the instrument was being assembled, Courtland's guide, astronomer Francesco Pepe, simply fished a shiny metal key off the lintel of the vestibule door. To get from one side of the cramped clean room to the other, Courtland had to negotiate a narrow and rickety wooden bridge—sans handrail—built over the instrument itself. "Falling in was not an option, but it seemed like a very distinct possibility," she says.

Her fears of losing her balance and becoming infamous as the journalist who wreaked havoc on HARPS-N proved unfounded. Courtland was soon transfixed by the sophistication and scientific promise of the technology, which will help characterize some of the most Earth-like environments outside our own solar system. The device may even play a role in the first conclusive identification of another planet capable of supporting life as we know it. That would be a momentous achievement. For more on this remarkable instrument, see Courtland's report, "In Search of Alien Worlds," in this issue. ❑

FRANCESCO PEPE

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 Data is in *IEEE Spectrum*, Vol. 49, no. 1 (INT), January 2012, p. 64, or in *IEEE Spectrum*, Vol. 49, no. 1 (NA), January 2012, p. 80.

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JOSEPH CALAMIA is a freelance writer based in New Haven, Conn. Despite the geographic disadvantage, he was the natural choice to write "China's Homegrown Supercomputers" [p. 54], because he'd reported on the development of the key microprocessors involved less than a year ago. A frequent contributor to *IEEE Spectrum* and an alumnus of the MIT Graduate Program in Science Writing, Calamia has also written for *Discover* and *Popular Mechanics*.

SALLY WIENER GROTTA and **DANIEL GROTTA** are a husband-and-wife team who have been writing about digital imaging, photography, and printing since the early 1990s. They make their *Spectrum* debut with a review of Adobe's new Creative Cloud and Touch Apps suite [p. 16]. Over the course of three days, Sally tore into the six cloud-based apps, testing every aspect of the programs with her own digital art. "I'm a fine arts photographer," she says. "So instead of using the test images, I just pulled images from my vast library of people, scenes, and animals"—even a snapshot of her husband that she morphed into a pirate.

JAMES OBERG, who wrote "Up, Up, and Away" [p. 48], which looks at recent progress in the private spaceflight industry, worked as an aerospace engineer at NASA for 22 years. He switched to journalism in the late 1990s and now makes his living reporting on space for such outlets as *Popular Science*, NBC News, and of course, *Spectrum*.

RICHARD STEVENSON, who wrote "LEDs for Less" [p. 33], on the coming revolution in lighting, is himself an expert on the raw materials that go into such devices: compound semiconductors. He got a Ph.D. at the University of Cambridge studying these materials. Then he went into industry and made them. Now, as a freelance journalist based in Wales, he writes about them. (His previous feature for *Spectrum,* however, was on good old silicon: "A Driver's Sixth Sense," October 2011.)

LAWRENCE ULRICH set out from San Francisco to drive 180 fume-free kilometers in an all-electric Nissan Leaf, without succumbing to "range anxiety." He recounts the logistics of the journey in "State of Charge" [p. 50]. The native Detroiter worked in the 1980s as a rock musician, playing keyboard as far afield as Europe before becoming a writer, specializing first in business, then in cars. He lives in Brooklyn, N.Y., and regularly writes for *The New York Times* and *Automobile*.

PAUL WALLICH, when not reporting on oddball technologies, takes to his shop to make small household parts by casting, carving, forming, filing, sawing, drilling, riveting, tapping, soldering, gluing, sanding, and polishing. He has been following digital 3-D printing since its early, hobbyist days; in "Taking Shape" [p. 57], he shows how it's now changing manufacturing.

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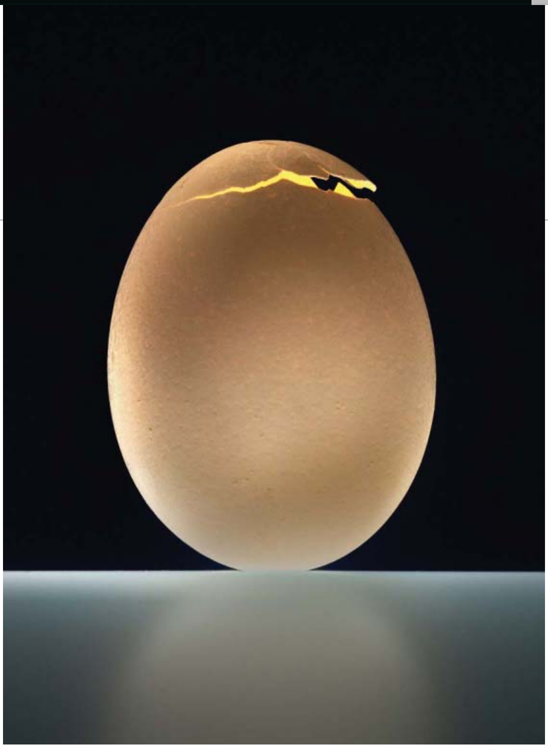

DAVE BRADLEY/GETTY IMAGES

Taking Innovation for Granted

THERE'S A theory making the rounds that technological innovation is slowing down and thus can no longer support the economic growth we've come to expect. It's not normally the sort of thing *IEEE Spectrum* would cover—we write about innovation rather than its absence. And indeed, as we cast about for examples of promising tech developments that will make news in 2012, the only problem we faced was in deciding which ideas *not* to include in the issue.

But the possibility of a tech slowdown that rattles the global economy can't be dismissed. Look, for instance, at the dearth of fundamentally new drugs coming down the development pipeline. Or consider that the speeds at which we travel are no better, and are in some cases worse, than they were in the 1960s.

The basic argument was set out two years ago in an e-book called *The Great Stagnation*, by Tyler Cowen, an economist at George Mason University, in Fairfax, Va. He contends that our innovations increasingly consist of refinements to established technologies, most of them hatched decades or even lifetimes ago: electric power, radio, automobiles, airplanes, rockets, hybrid crops, antibiotics. In Cowen's phrase, we have plucked the "low-hanging fruit" and must strain ever harder to get anything delectable from the aging tree.

Interestingly, Cowen makes a grudging exception for electronics and information technology, which continue to barrel ahead. And as we assembled this issue, we found support for the idea that not only is electronics robust but that it continues to nurture innovation in plenty of other fields. In the pages that follow, you'll learn how 4G LTE is pushing the fusion of computing and communications to new heights and how efficient electric-drive cars are going mainstream; you'll read about improvements in LED lamps, medical applications of robotics, and the realization of one-off manufacturing via 3-D printing. We also note that researchers seem to be closing in on one of the most awe-inspiring goals in all of science: finding an extrasolar "Goldilocks" planet—one that's not too hot and not too cold to support life.

But even in electronics there are unsettling developments. The evidence, too, is in this issue. Moore's Law—the backbone of the IT revolution—now faces by far the most onerous obstacles in its long history, and measures to keep it going are getting ever more heroic. This month, we cover two measures—3-D chips and extreme ultraviolet lithography—that had long been resisted because of their great expense. Now the industry is betting heavily on them, mostly because other options smack more of desperation than of heroism.

So taken for granted is technical innovation that any interruption in its progress is treated as an aberration. But breakneck progress is hardly the norm. As the economic historian Gregory Clark pointed out in his 2007 book *A Farewell to Alms*, the average standard of living in the world was the same in 1790 as in the Neolithic Age. When he looked past the lace-and-velvet portraits of the long-dead rich to examine the food consumption of the average peon, he found that it hadn't risen from Adam to Adam Smith.

Clark argues that although technology did advance in every age, the advances came too slowly to stop people from breeding themselves back into poverty. For eons, he says, we dangled at that level of subsistence that ecologists call the Malthusian limit. The Industrial Revolution broke through that limit with a string of technologies of such power that any one of them would be big news today. Together they fell on our forebears like an avalanche, increasing their productivity so fast that, try as they might (and try they did), they couldn't make babies fast enough to stay poor.

Just why that revolution came where and when it did is still not clearly understood. Whether it can go on forever is by no means assured. True, nobody now speaks of actually going backward. For one thing, population growth appears to be slowing; for another, countries long outside the circle of progress are at last catching up. For them, the low-hanging fruit still lies within reach.

But if we don't get innovation back to what we would like to regard as normal levels, we will have to change our way of thinking. If our prosperity depends on rapid technical progress and such progress does not come, then all our economic calculations must be revised downward. "We are not as rich as we thought we were," concludes Cowen.

It is the challenge of the entire research community to change the trend line and prove him wrong.

—PHILIP E. ROSS

IEEE spectrum Previous Page | Contents | Zoom in | Zoom out | Front Cover | Search Issue | Next Page

update

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Helicopters Go Electric

Electric flight takes on the final frontier

The past six months have seen some remarkable advances in the budding world of electric flight, in a realm where until now internal-combustion engines have held firm: helicopters. Three separate demonstrations—of an electrically assisted helicopter and two tiny but fully electric choppers—suggest that the era of electric whirlybirds can't be far away.

The first development took place in early July 2011, when pilots at Eurocopter, the world's largest helicopter manufacturer, based in Marignane, France, test-flew a single-engine chopper that had been fitted with lithium-ion batteries and an auxiliary electric motor intended to help out in case of engine failure. Helicopter pilots deal with such emergencies using a technique called autorotation, which requires some deft manipulation of the helicopter's rotor when power first cuts out and again when the helicopter nears the ground. According to Jean-Michel Billig, executive vice-president for R&D at Eurocopter, the hybrid electric system his group designed provides the brief bursts of power needed at those two critical moments. "We're not talking about minutes here—we're talking about seconds," says Billig. With the new system, engine-off landings were "extraordinarily comfortable" from the pilot's perspective, he says.

Eurocopter is not the only helicopter manufacturer experimenting with electric power. Since 2008, Sikorsky Aircraft Corp. has been working to remove the normal piston engine from a small helicopter, a Sikorsky S-300C, and replace it with an electric motor, a demonstration project it calls Firefly. Sikorsky,

BATTERIES INCLUDED: Sixteen brushless motors sent Thomas Senkel flying for the first time this past October.
PHOTO: E-VOLO

update

based in Stratford, Conn., has been showing its modified S-300C at aircraft exhibitions but so far has not flown it.

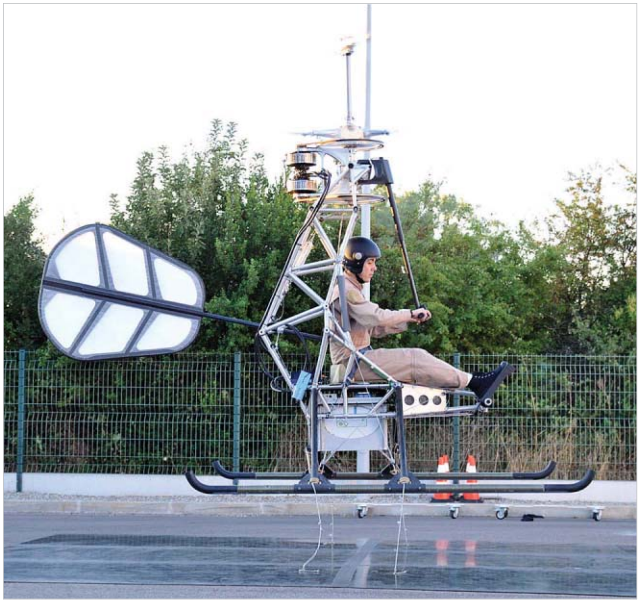
So it came as a surprise to some when another group beat the venerable helicopter company into the air, in the year's second stunning development in electric flight. Solution F, a French company that builds race-car engines and associated equipment, underwrote the development of what in August became the first manned electric helicopter to take off and land on its own power. It was the result of an unlikely collaboration.

Pascal Chretien, an independent engineering consultant and commercial helicopter pilot, began working two years ago for Solution F, which was then starting to explore the helicopter-engine market. Chretien floated the idea of designing a hybrid-electric power plant, which he viewed as inherently safer than traditional designs for helicopters. That sparked discussions of building the world's first all-electric helicopter instead, a notion that captivated the imagination of this unlikely team. Chretien set about designing such a craft in mid-2010. "I pretty much did all the work as a volunteer," says Chretien. Solution F paid for everything else.

Chretien's design uses two counterrotating rotors, one on top of the other, spinning around the same axis, to avoid the need for a power-sapping tail rotor. Each of the main rotors is driven by a brushed DC motor, with a bank of lithium-ion batteries mounted under the pilot's seat. "The machine has buckets of power," says Chretien, although the maximum flight duration demonstrated so far is just 6 minutes.

"Sikorsky was in the race, and we thought they would be flying quickly, and we really wanted to fly before them," says Chretien. "Solution F didn't want to be the second one." He admits that he took some calculated risks with his design to get it into the air fast and that his prototype is far from anything you could sell. As it turns out, Chretien did have some close competition for the honor of building the first manned electric helicopter to fly untethered—but not from Sikorsky. It came from a German team that accomplished another manned electric-helicopter flight at the end of October, the third milestone in electric rotorcraft technology in the span of just four months.

Work leading up to that flight began in 2009. It was then that Thomas Senkel (a physicist who has worked on various electric vehicles), Stephan Wolf (a software developer), and Alexander Zosel (a businessman) started thinking about building an electric quadrocopter—like the four-rotor designs that many radio-control modelers fly, only big enough to carry a person. "After discussing it for three months, we said, 'Okay, let's do it,' " says Senkel.



LIFTOFF: Pascal Chretien tests this record-setting electric helicopter.
PHOTO: SOLUTION F

The design they ultimately came up with resembles four radio-controlled quadrocopters flanged together—16 rotors in all. "If you have less, there's not enough redundancy," says Senkel. "If you have more, it would be too complex." Lithium-ion batteries and motor controllers are strapped to the spidery contraption's aluminum frame near each motor, eliminating the need for heavy cabling. The physical design is stunningly simple, although there's more to it than meets the eye, Senkel says.

Their first craft is just a proof of concept, but the German trio has formed a company, called E-volo, to explore commercialization of their design for the ultralight-aircraft market. Senkel thinks such a vehicle would cost considerably less than a conventional helicopter—more in line with the cost of a car. "Most helicopters have a lot of mechanics that have to be maintained and could fail. We don't have that much stuff," he says.

"We congratulate [Solution F and the E-volo group] for moving the needle forward," says Jonathan Hartman, who heads Sikorsky's Firefly project. Given the head start and resources that Hartman's team had, Chretien remains surprised that he was able to beat Sikorsky into the air. But, he says, "One thing's for sure: The day they start flying, it'll fly a lot better than ours." —David Schneider

IEEE spectrum Previous Page | Contents | Zoom in | Zoom out | Front Cover | Search Issue | Next Page

10 x 10 nanometers Area of what could be the smallest resistive RAM cell ever made. Researchers at Imec, in Belgium, described the device last month at the IEEE International Electron Device Meeting.

Metamaterials Make for a Broadband Breakthrough

Patent house Intellectual Ventures and others aim at better wireless broadband

SINCE 2008, frequent fliers have relished the luxury of onboard Internet connections. Today, service relies on a fixed antenna that picks up signals from a nationwide network of cell towers. But that method offers low bandwidth at sometimes ridiculous prices. New antennas based on metamaterials, though, may soon rescue Web-addicted travelers from poor and pricey connections in the air, and a group at the patent-licensing firm Intellectual Ventures (IV) thinks that it can implement the new technology by 2014.

Ideally, airlines would be able to direct dynamic antennas straight up at satellites, which can be done two ways: mechanically, with a gimbal that points an antenna to the right part of the sky, or with a phased array, which electronically directs a beam by pulsing individual elements of an array in precise patterns. But gimbals are not exactly aerodynamic—one example is that massive protuberance on the nose of the Predator drone. And the many phase shifters needed for phased arrays make them extremely expensive—about US $1 million a pop.

With options like these, companies like Boeing are itching for a low-cost, low-power, electronically scanned array, a technology that IV's metamaterials researcher Nathan Kundtz calls "the holy grail of antenna design."

The group at IV has developed a thin, lightweight antenna that takes advantage of metamaterials—synthetic substances that are being researched for use in "invisibility cloaks," among other things. While natural substances derive their electromagnetic properties from their atomic composition, metamaterials gain theirs from fine, deliberately designed internal structures, which, although larger than atoms, are smaller than the wavelengths of light they manipulate.

"Using metasurfaces for antennas is very similar to the concept used in cloaking," says IEEE Fellow Stefano Maci, a professor of electromagnetics at the University of Siena, in Italy, who is working on a separate but similar metamaterials-based antenna for the European Space Agency. The subwavelength features of metamaterials produce electromagnetic properties that bend optical and radio waves in ways once thought to be impossible, allowing cloaking devices to refract light around an object, or antennas to steer beams.

Metamaterials-based antennas are already found in some cellphones and wireless routers, which use their small size and range-boosting ability to great effect. These antennas are also cheap: Metamaterial elements can be easily printed using standard lithographic techniques.

In an antenna, a radio wave propagates along a low-loss circuit board material that's printed with hundreds or thousands of individual metamaterial elements. Each of those elements can be tuned to resonate at a specific frequency and to redirect radiation. As the surface wave passes beneath the elements, waves of radiation emit from the surface at different angles, depending on how each element is tuned. Interference between those waves of radiation produces a beam in the direction and shape desired.

Today the real problem isn't constructing those antennas. Instead, "the most difficult

RADIO ROW: Individual metamaterial elements like these can be tuned to dynamically redirect radio waves. *IMAGE: INTELLECTUAL VENTURES*

NASA/GSFC

news brief

Illuminating Epidemics

Researchers led by a Princeton University scientist say they've found a way to track flare-ups of epidemics by measuring the change in nighttime lighting as seen by satellite. They observed that measles outbreaks were coincident with an increase in the lighted area around Niger's three largest cities: Agricultural workers gather at the cities during the dry season, leading to overcrowding and promoting the spread of disease. The data can also be used to predict malaria and meningitis, say the researchers.

ieee spectrum | Previous Page | Contents | Zoom in | Zoom out | Front Cover | Search Issue | Next Page | Qmags THE WORLD'S NEWSSTAND®

4.5 terawatts Peak potential for electricity production by high-altitude airborne wind generators, according to German researchers. That's a serious drop from an earlier estimate of 1750 TW.

update

step is to reconfigure and maintain a good shape of the beam over the bandwidth," says Maci. That's important on a bucking plane—or train or automobile—that needs to keep in constant contact with a satellite. In order to fluidly redirect a beam, the frequency and direction of each individual element needs to be controlled on the fly.

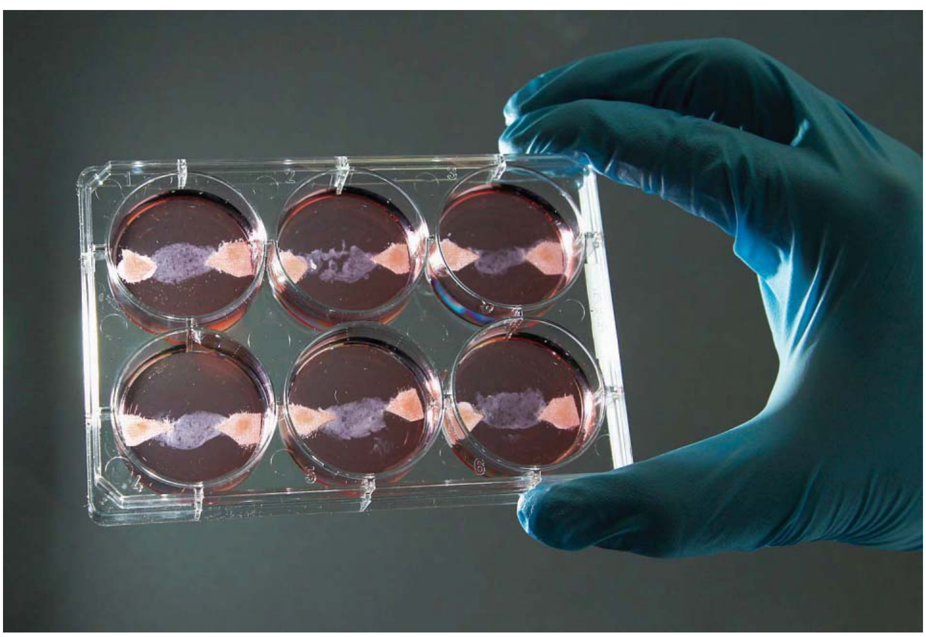
There are a number of ways to do that, says Kundtz. "In the nascent stages of the project, we outlined about 10 different ways we could change a cell's properties," he says, including ferroelectric materials, microelectromechanical systems devices, and liquid crystals. IV won't disclose what it has settled on yet. "We found a very inexpensive way of tuning each one of those elements," says Russell Hannigan, director of business development at IV. "By applying a voltage across [an element], you can scatter energy whatever way you want to across the surface."

Antenna researchers express some disbelief at IV's claims: In just two years, the company professes to have achieved a degree of reconfigurability that others have struggled with for much longer. A group at HRL Laboratories led by IEEE Fellow Daniel Sievenpiper, now at the University of California, San Diego, has developed a working metamaterial antenna. However, "more research and development is needed to achieve the performance of today's phased-array technology for electronic beam steering," says Joe Colburn, director of antenna research at HRL. Maci is skeptical of the group's work without further evidence of their methods. "In principle, it is possible to achieve what they claim," he says. "But it's extremely difficult to do."

IV's metamaterials antenna isn't yet ready for production. The researchers first demonstrated 2-D steering only this June, and they're aiming to have a product by late 2014. Before then, they'll need to improve the efficiency of their antenna, one of the historical banes of metamaterials, says Kundtz.

But that should be a surmountable obstacle. Says Maci: "I believe this will be the future of reconfigurable antennas."

—Katie M. Palmer



FRANCOIS LENOIR/REUTERS

Living Off the Fat of the Lab

Meat production may be moving from the pasture to the petri dish. Mark Post, a researcher at the University of Maastricht, in the Netherlands, is growing strips of animal flesh in his lab and says he hopes to produce an in vitro hamburger patty in the coming year. The cultured meat begins as stem cells taken from animals and is fed a mixture containing just the right amount of fat, protein, and carbs. Growing meat this way will solve several problems, says Post. We'll be able to put land to better use, reduce greenhouse-gas emissions from livestock, and fine-tune the meat we eat so that it's healthier for us.

ieee spectrum | Previous Page | Contents | Zoom in | Zoom out | Front Cover | Search Issue | Next Page | Qmags THE WORLD'S NEWSSTAND®

LISA R. ADAMS/GETTY IMAGES

Electronic Cotton

Circuits could be woven from conductive and semiconducting natural fibers

A GROUP OF researchers in the United States, Italy, and France have invented transistors made from cotton fibers. They envision such devices being woven into clothing capable of measuring pollutants, T-shirts that display information, and carpets that sense how many people are crossing them. "We want to create a seamless interface between electronics and textiles," says Juan Hinestroza, director of the Textiles Nanotechnology Laboratory at Cornell University, in Ithaca, N.Y.

Instead of attaching sensors or processors to clothing after the garments are fully formed, it would be more effective to incorporate such devices directly into the fabrics, says Annalisa Bonfiglio, an EE professor at the University of Cagliari, in Italy, whose student Giorgio Mattana worked on the cotton in Hinestroza's lab.

The cellulose that makes up cotton is naturally insulating, so to make a fiber conductive, the team coated each strand with gold nanoparticles. They then added a thin layer of a conductive polymer known as PEDOT. The fibers proved to be about a thousand times as conductive as plain cotton, while their mechanical properties remained almost unchanged. They were slightly stiffer but more elastic than untreated fibers, Bonfiglio says. The team demonstrated the treated cotton's conductivity by making a simple circuit, knotting one end to a battery and the other to an LED.

To show the versatility of the process, the researchers created two types of devices: an organic electrochemical transistor and an organic field-effect transistor. For the electrochemical version, conductive cotton fibers were used as source, drain, and gate electrodes. To complete the transistor, the team needed to create a semiconductor. They achieved this by doping the conductive polymer with poly(styrenesulfonate), a polymer commonly used to make proton exchange membranes in fuel cells. After a soak in the second polymer, the cotton fiber was coated with ethylene glycol to make it waterproof.

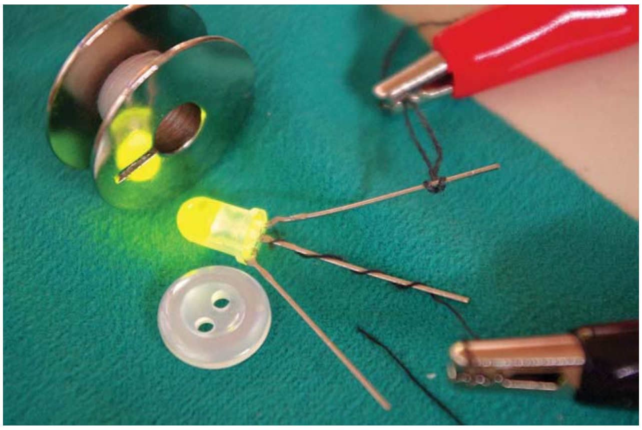
The field-effect transistor also begins with a conductive cotton strand dipped in the semiconducting polymer, which in this case acts as the gate electrode. But the fiber is then given a thin coat of polymer film that acts as a dielectric, followed by a coat of pentacene, another semiconductor polymer film.

Treating the cotton with these various substances is not as complicated as it sounds; Bonfiglio says it's comparable to dyeing the material. Still, don't expect to see underpants doubling as MP3 players anytime soon. The speed of electrons in these transistors is relatively low compared to that of silicon circuits, says Bonfiglio.

"For the moment, I think the most realistic application is in the sensor area," she says. For instance, firefighters' uniforms might be able to detect dangerous chemicals, while security personnel could be alerted to airborne signatures of explosives or drugs. Garments might also monitor heart rate or perspiration. Inside homes and businesses, fabrics—in the form of carpeting, wall coverings, and upholstery—could keep track of humidity levels and allergens.

"If you think about how many fibers you have in your T-shirt, and how many interconnections you have between the weft and the warp of the fabric, you could get pretty decent computing power," says Hinestroza.

—NEIL SAVAGE



NICE THREADS: Conductive cotton ties in to a simple circuit.
PHOTO: TEXTILES NANOTECHNOLOGY LABORATORY AT CORNELL UNIVERSITY

spectrum | Previous Page | Contents | Zoom in | Zoom out | Front Cover | Search Issue | Next Page

A Flat Transistor Comeback?

SuVolta is pursuing precision doping in its bid to compete with 3-D transistor technology

AFTER YEARS of doping, straining, shrinking, and tweaking, engineers seem to have exhausted all their strategies for improving the planar complementary metal-oxide semiconductor (CMOS) transistors at the heart of today's computer processors. Producers of cutting-edge chips are now resorting to new structures—building up in three dimensions or constructing transistors in ultrathin layers of silicon—to ensure that devices keep shrinking and that Moore's Law keeps going just a bit longer.

But semiconductor start-up SuVolta is betting that its take on the traditional planar structure, called Deeply Depleted Channel (DDC) transistors, can go toe-to-toe with the new alternative designs. The firm hopes to build a business licensing a technology it says will reduce power consumption and boost performance with minimal changes to the way transistors are made.

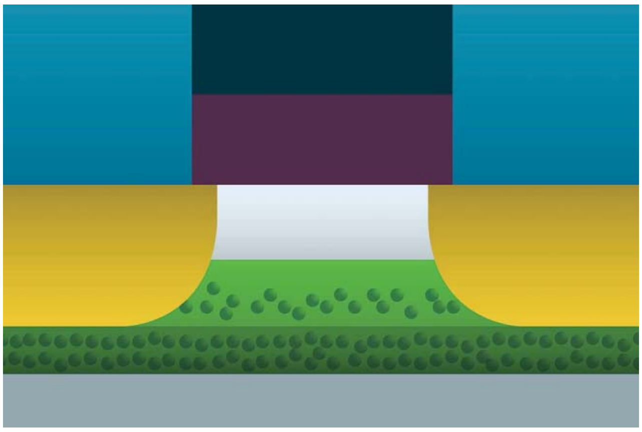
The trouble with today's planar transistors is twofold: When you try to make them smaller, they leak current and waste power. Just as troubling is that the more you shrink them, the harder it gets to make them uniform enough for one transistor to behave the same as the next.

To some extent, both problems are caused by unavoidable variations in the number of dopant atoms in the silicon. Silicon is traditionally doped with elements like boron or phosphorus in order to create and fine-tune the energy barriers that both block and permit current to flow. Electric fields are used to steer streams of dopants into the silicon.

But as chipmakers have reduced the size of CMOS transistors, the total number of dopant atoms in a key part of the transistor, the channel, gets smaller. The channel is used to carry current between the source and the drain, and it's controlled by a gate that is typically mounted on top of the channel. The fewer dopants there are, the stronger the influence of random fluctuations in the dopant concentration. These fluctuations have come to have a strong impact on a transistor's electronic properties, resulting in a high proportion of less-than-ideal transistors that leak more power or switch more slowly than designed.

SuVolta hopes to make transistors less leaky and more predictable by changing the way their channel regions are doped. Instead of evenly doping a transistor channel, the company's strategy is to lay down the channel in three layers, each about 50 to 100 angstroms thick and each with a different concentration of dopant.

Under the influence of the gate's voltage, current moves primarily through the topmost layer of silicon, which contains no dopants at all. The middle layer allows for some fine-tuning of the voltage needed to turn the transistor on or off. And the bottom layer in SuVolta's transistor is heavily



LOW PROFILE: In this Deeply Depleted Channel transistor, layers of silicon are doped to increasing concentrations [top to bottom]. Current flows through the top [gray] region and is blocked from leaking out by the highly doped bottom layer [dark green]. *IMAGE: SUVOLTA*

doped, blocking the gate's electric field and preventing it from creating a path through which current could leak.

SuVolta says that 65-nanometer transistors (the cutting-edge size in 2006) made with its technique boast half the variation in the threshold voltage of ordinary CMOS transistors and leak just 20 percent as much power. "That's actually a very, very impressive number," says Seok-Hee Lee, an electrical engineering professor at the Korea Advanced Institute of Science and Technology in Daejeon, South Korea, who formerly worked on process integration at Intel.

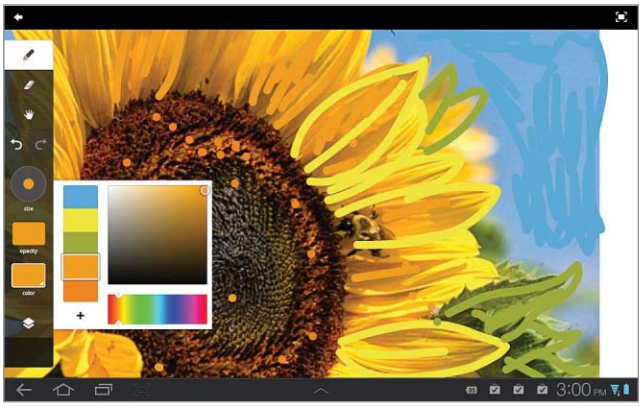
Lee also believes the simpler structure should be easier to produce than the two alternatives the chip industry is faced with now—the FinFET and the ultrathin-body SOI transistor. "I think this will extend the planar transistor architecture," Lee says.

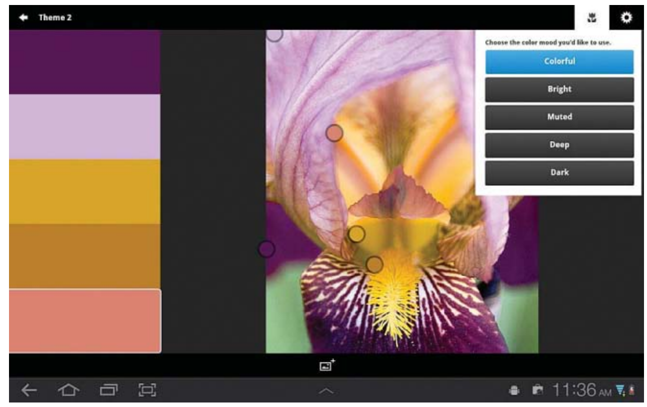
"From a technical standpoint, it's a solid approach," says Tsu-Jae King Liu, a professor of electrical engineering and computer science at the University of California, Berkeley, and a coinventor of both alternative transistor designs.

But, Liu adds, it remains to be seen exactly how well SuVolta's strategy will compete against FinFETs and ultrathin-body transistors. That will depend on how well the company can control the sharpness of the boundaries between differently doped layers, she says.

SuVolta has marketed its DDC transistors as an alternative to FinFETs and ultrathin-body SOI architectures. And Scott Thompson, SuVolta's chief technology officer, says the company believes it can scale the devices down so that their smallest features are just 14 nm. But he says these devices will likely have more of an impact for semiconductor companies with transistors whose smallest features are between 20 and 30 nm—the size range that's state of the art in the chip industry today. The idea is that the DDC design will allow companies to continue performance improvements without the expense of actually making smaller transistors. "The next 10 years, there's still going to be a lot of progress from Silicon Valley," says Thompson. "It just won't come from making things smaller."

—Rachel Courtland





REVIEW: ADOBE'S CREATIVE CLOUD AND TOUCH APPS

A new product suite for tablets heralds Adobe's move from desktops to clouds

CLOUD COMPUTING is turning our world inside out. Once, we switched on our computers and then ran software that loaded our words, images, movies, and other stuff. Now the "stuff" is at the center of the universe and can be loaded anywhere there is a computing device. Adobe, which makes many of the programs that we use to create and alter that stuff, has begun the process of turning itself inside out.

It started this past November when the company launched Adobe Creative Cloud, a new initiative that includes a cloud-based file-storage organizer (also called Creative Cloud) and Adobe Touch Apps, a suite of six imaging apps for Android (with iOS versions to follow early this year).

Next, Adobe will deploy Creative Suite 6 (the newest versions of Photoshop, Illustrator, Premiere, and its other core desktop imaging applications) via the Web—with Creative Cloud (CC) as the hub. And it's a good thing. Don't expect the power and sophistication of Adobe's desktop applications from the apps; instead, they offer the digital equivalent of the classic cocktail napkin sketch—a quick idea jotted down over drinks.

In this product review, we'll look at the hub and Adobe Photoshop Touch. (We've also reviewed the five other Touch Apps online: Adobe Kuler, Adobe Collage, Adobe Ideas, Adobe Proto, and Adobe Debut; see http://spectrum.ieee.org/adobecloud0112.) We used a Samsung Galaxy Tab 10.1, which Adobe loaned to us for our testing.

Still in public beta, CC is a classic, albeit limited, Web-based file-management and storage system for sharing files among the various new Touch Apps and Adobe's desktop imaging programs. Files saved on it are accessible from any device through a Web browser. All uploads from your desktop computer are done via the Web, though we expect that soon (probably with the release of Creative Suite 6) you'll save directly from your desktop applications to the cloud.

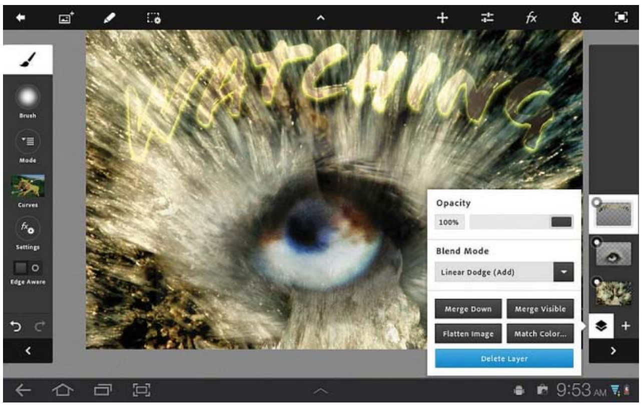
CC supports several formats, including JPEG, PNG, PDF, Adobe Photoshop (PSD), Adobe Illustrator (AI), Adobe InDesign (INDD), and different flavors of RAW. While the Touch Apps can't use most of the supported formats, the apps and CC are well integrated, with files accessible from within the apps' interfaces. Exporting from the apps to CC requires tapping the Upload command before selecting the files, which we found counterintuitive.

While you can rename individual files and folders—and move files between folders—you can't reorder them, nor can you view image metadata, so you can't use keywords for searches. Even embedded copyright notices are hidden.

There was no lag when we leafed through a 48-page PDF that we imported into CC. In addition, a downloadable Kuler color swatch is automatically calculated from the picture and displayed alongside it. (See the online review for more about Kuler.) When you share a file from CC, the recipient receives an e-mail with a link to that image in your CC account.

The public beta of CC is clearly a work in progress. Many functions are bogged down with time-consuming tasks that were super-annuated long ago with more efficient workflows. But its basic structure is sensible, and the control over layers and pages within complex files offers some new creative possibilities.

Of the six Touch Apps offered, Photoshop Touch



THE POWER OF TOUCH: With tools for retouching, layering, and painting with special effects, Photoshop Touch is the most full-featured of six new Adobe Touch apps for tablets. You can even import an image taken with the tablet's camera into a layer. The apps work with Adobe's new network service, Creative Cloud. *IMAGES: SALLY WIENER GROTTA & DANIEL GROTTA*

is, not surprisingly, the most full-featured. After all, it is based on Adobe's flagship application.

PS Touch can import JPEG, PNG, GIF, PSDX, and PSD photos from CC or the tablet's camera. PSD files can be opened only via CC, where the file is converted. The conversion flattens layers and removes other information that Photoshop Creative Suite supports but PS Touch doesn't. PS Touch images are limited by the tablet technology to 1600 by 1600 pixels, with a maximum of 16 layers.

In many ways, PS Touch is reminiscent of early Photoshop technology. For instance, its editing is destructive: Selections can't be saved, special effects and fades are merged into the underlying layer, and text is rasterized immediately. (The layers themselves, though, do remain intact and can be exported out to Photoshop CS version 5 or later.)

Despite these limitations, PS Touch has some new options that current Adobe products lack. For example, the brush tool allows you to paint not only with color but also with special effects.

PS Touch has a nice collection of selection tools for choosing areas of different pictures to combine into a composition, including a circle, a rectangle (with optional curved corners), a lasso, and a magic wand. But given the limitations of working on a tablet, it's difficult to create a precise selection, even when using a stylus. PS Touch's version of the classic blue-screen technique, called Scribble Select, does an imperfect but decent job of removing the background.

When you upload a file from PS Touch to CC, it's saved in Adobe's new PSDX file format. To use it in Photoshop CS5 or later, you'll need to download a free plug-in from http://www.adobe.com/go/rg_plugins. In our tests, the layers created in PS Touch stayed intact when imported. When you save to the tablet's gallery, share via e-mail, or upload to Facebook, PS Touch automatically converts files to the JPEG format, with no control over the amount of compression.

Once you stop expecting PS Touch to act like Photoshop CS or even Photoshop Elements and accept it for what it is—a limited app with some great functionality—using it can become quite intoxicating, resulting in images you might have never come up with on your desktop. However, the limited-resolution PS Touch–generated files are more suitable for client comps and Web sharing than for printing.

According to a November posting on Adobe's blog, CC will cost US $50 to $70 per user per month; you can buy Touch Apps separately for $9.99 each. Currently, 20 gigabytes of cloud storage is included in the purchase of your first Touch App, but you receive no additional storage space when you buy additional apps.

—SALLY WIENER GROTTA & DANIEL GROTTA

TECH SPECS

OPERATING SYSTEM
Android 3.1 or higher, but not 4.0 (Ice Cream Sandwich)*

TABLET DISPLAY SIZE
8.9 inches or larger

DISPLAY RESOLUTION
1280 by 800 minimum

CAMERA
Recommended

STYLUS
Recommended**

**According to Adobe, at press time, some remaining software bugs were preventing the Touch Apps from working with Android 4.0; as soon as they are resolved, the apps will be compatible with the latest Android OS.*

***Adobe Touch Apps support stylus pressure sensitivity on those tablets that offer it.*

NOTE: Given these specs, Adobe Touch Apps will not work on some Android tablets. For instance, both the new Kindle Fire's screen and the Samsung's Galaxy Tab 7.0 are too small.

ieee spectrum Previous Page | Contents | Zoom in | Zoom out | Front Cover | Search Issue | Next Page Qmags THE WORLD'S NEWSSTAND®

tools & toys

NOT YOUR PARENTS' SCRABBLE

Words with Friends reinvents a 64-year-old board game for the iPhone era

RANDI SILBERMAN KLETT

IF YOU know the name Zynga, chances are it's in the context of the company's blockbuster Facebook game, *FarmVille*. But even as Zynga spreads its roots through the fertile soil of social networks, it's also decided to take on the next big trend in computing—mobility. In 2010 it acquired NewToy and its online game, *Words with Friends*, an update of the venerable board game Scrabble.

"When the iPhone came out, we saw this game platform that you carry around with you all the time," says Paul Bettner, who along with his brother David helped design the new game. The Bettners and their design and engineer partners, particularly Kevin Holme and Shawn Lohstroh, had stumbled upon a new world of casual gaming.

"We had no idea that it'd catch on like it did. It was just something that we wanted to play," Bettner recalls. "I wanted something I can pull out and play for a few minutes and then put it back in my pocket."

A billion supermarket-queue game plays later, Zynga is sitting on a *Words with Friends* empire that has, in three years, become as much of a global social phenomenon as the 64-year-old game it's loosely based upon.

Like Scrabble, *WwF* is a crossword puzzle–like game that rewards verbal tinkerers and linguistic esotericists.

But *WwF* is not a copy of Scrabble. Holme combed Internet databases to find the most common letters in everyday English usage. "He came up with a percentage for each of the 26 letters," Bettner says. "And that was just the starting point."

Holme then set a designer's eye on reinventing a style of game that originated when veterans were still returning home from World War II. He reshaped the board, added four tiles, and changed the values and distribution of the letters.

"One of the goals we had in designing our letter distribution was to give players letters that would allow them to form words much more easily than in other word games," Holme said via e-mail. "In *WwF*, we put four *H*s into the bag and set their value to 3—a big difference from Scrabble, which uses two *H*s worth 4 points."

In other words, he amplified the number of what Bettner calls the game's "explosive moments."

"Creating a fun social game, especially for a very broad audience, is about finding the right balance between randomness and skill," Bettner says. "If there's just that right amount of randomness in the game, then you feel like, I'm pretty far behind, but I might just get the perfect combination of letters to spell a word with a *J* in it."

Andrew Thomas, a visiting assistant professor of statistics at Carnegie Mellon University, has run millions of simulations of *WwF* and Scrabble games in software. The simulations show how each letter either adds to or detracts from a player's average game score. Thomas sees the letter *J*, which *WwF* values at 10 points versus Scrabble's 8, as an example of how *WwF* creates explosive game play. (For more on Thomas's simulations, see "Data Mining Scrabble," in this issue.)

"*J* is almost a break-even tile in standard Scrabble," he says. "On average, you're no better or worse getting it on your rack. In *WwF*, it's extremely advantageous to have the *J*—to the tune of 6 final score points," Thomas says.

The original Scrabble game has finally migrated from its "Father Knows Best" origins—when families had the time and inclination for a night of board games—to smartphones. We'll see how well it competes with a game that was designed from the ground up to be played at bus stops as well as in living rooms. —MARK ANDERSON

books

ENERGETIC WRITING: Geopolitics, energy, and technology come together in *The Quest*. PHOTO: DINA RUDICK/ THE BOSTON GLOBE/GETTY IMAGES

Beyond Oil

Daniel Yergin's new book is required—and delightful—reading

DANIEL YERGIN, probably the best-known and most widely quoted American in all matters having to do with energy, is in the spotlight again with a big new book.

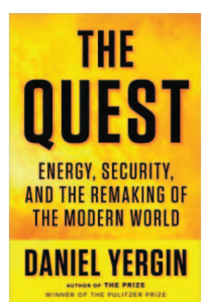
A very young Yergin made his reputation in 1977 with *Shattered Peace*, an analysis of the origins of the Cold War. He consolidated that reputation in 1991 with *The Prize*, which won a Pulitzer Prize and gave him a second career as an energy consultant. He demonstrated in both books a gift for entertaining the general reader while also satisfying specialists—no mean trick.

He has done it again, differently, with *The Quest*, a comprehensive survey of the global energy scene that focuses on developments of the last 10 years. While each of Yergin's first two books had one compelling story to tell, *The Quest* has many. Few readers, perhaps, will want to plow through it from beginning to end. But if you want to know what's been going on in oil exploration, unconventional gas, the alternative green technologies, biofuels, electric vehicles, or climate policy, you'll find that Yergin consistently provides judicious treatments laced with memorable anecdotes and colorful personalities.

Yergin's greatest strengths lie in his thought-provoking historical and geopolitical narratives. If you happen to wonder, for example, why the collapsing Soviet government let go of Ukraine, Belarus, and the "stans" with a flick of the wrist but then fought two nasty wars in Chechnya, you might consider how pipeline politics evolved during the 1990s in the Caspian and Caucasus regions. As Yergin notes: "The [preferred] Russian pipeline passed through Chechnya, where in that same year [1999] the second Chechen War would erupt between Russian forces and Islamic rebels. That conflict forced the shutdown of the Russian pipeline."

If Yergin has a weakness, it's a tendency to sometimes omit, amid all the fascinating detail he's delivering, the main thing we might want to know. Having described, for example, the immensely complex and expensive oil developments in Azerbaijan and Kazakhstan that ended up producing 2.8 million barrels of additional oil per day, he neglects to mention what proportion of world consumption that represents or how it compares to increases in China's oil demand in the same period.

For the record, 3 million barrels per day represents something less than 4 percent of daily oil consumption, and the increase in China's daily consumption during the period that the Azerbaijani and Kazakh fields were developed was almost certainly greater. It goes to show, as a former Shell CEO famously said, that the age of easy oil is over, and that from now on getting new oil will be tough in every way.



The Quest
Energy, Security, and the Remaking of the Modern World
By Daniel Yergin; Penguin, 2011; 816 pp.; US $38; ISBN 978-1594202834

Technology is not Yergin's main interest or greatest strength, and sometimes that leads him slightly astray. Curiously, he puts a chapter about solar energy ahead of one about wind, which has been the biggest single story in electricity generation in the last two decades.

Yergin tells a nice story about how California subsidies, combined with innovation at a Danish farm machinery company called Vestas Wind Systems, produced a wind revolution. But he doesn't mention the importance of techniques and materials borrowed from the aerospace industry or explain, really, how the modern wind turbine differs from the windmills that used to dot the Great Plains of the United States. By the same token, he doesn't seem to fully grasp how challenging it will be, technically, to get solar cells to match wind in cost and performance.

But those are quibbles. This is an excellent, comprehensive book that anybody interested in energy will want to own.

—WILLIAM SWEET

profile

GAME WORTHY

Kim Swift set out to design fun games that make her laugh

GAME CHANGER: Kim Swift's next game, *Quantum Conundrum*, comes out in 2012.
IMAGES: AIRTIGHT GAMES

KIM SWIFT was stunned the first time someone asked for her autograph at a game developers' conference.

"That was one of the most surreal moments of my life," she says. "I was like, 'Really? I'm really not special! I'm just making games that I want to play.' "

But in gaming circles, Swift, 28, is a rising star. Her first job was at Valve Corp., in Bellevue, Wash., where she and her student team were hired to revamp their college senior project into the hugely popular *Portal*. Now, as a creative director of a 16-member team at Airtight Games, she's readying another puzzle game, *Quantum Conundrum*, for a first-quarter release.

The premise: Your mom has sent you to your eccentric millionaire uncle, Professor Quadwrangle, for the weekend, but after a lab mishap, he goes missing. Your job is to track him down using your Inter-Dimensional Shift Device. You switch between five different dimensions to solve various challenges and traverse Quadwrangle Manor with the help of D.O.L.L.I., an eager object-replicating robot head. D.O.L.L.I. is less adept at replicating animals, hence the Professor's badly cloned cats Widget 1, 2, and 3, whose weird portraits adorn the walls for no apparent reason.

"Weird for no reason—that pretty much sums up the team as a whole," says Swift, laughing. "We're very silly people, and pretty much anything you see in the game that's like, 'What in the world is going on?' is just us having fun."

"Physics was my favorite subject in college," she says. "I love to take things we overlook or take for granted, like science fiction clichés or how gravity works, and just turn them on their head. I like making players think in a different way. What if portals and dimension shifting were more than just cool transitions between scenes or levels and were the game? That's what's fun about games—you get to live a weird fantasy. My fantasies are just a little odder."

As a Houston high school student, Swift already knew she wanted to create games, so she enrolled at DigiPen Institute of Technology, in Redmond, Wash., a four-year gaming conservatory that teaches art and engineering students how to create games. "I was already a decent artist," she says, "so I majored in real-time interactive simulation, which essentially boils down to a computer science degree with a specialization in computer graphics and physics."

Swift's senior gaming project, *Narbacular Drop*, which she developed with six classmates, caught the attention of Valve for its unique use of portals. The company hired them after their 2005 graduation to repurpose their core gameplay concept using Valve's proprietary software. The result, *Portal*, became an unexpected hit in 2007.

Two years later, Swift—who had left the *Portal 2* team over creative differences and switched to Valve's shooter-game projects *Left 4 Dead 1* and 2—caused ripples in the industry when she quit and joined Airtight Games, in Redmond. "I always had this hankering to go back and make more games like *Portal*, but Valve was more interested in focusing on games for a more hard-core audience. So I got the opportunity to come to Airtight Games as a creative director and lead a team making puzzle games for a broader demographic."

"As creative director," she says, "I touch upon a little bit of everything in the game—art, level design, writing, scripting, some PR, and sometimes making sure the coffee is stocked—but day to day, I make sure the game comes together as a whole and is fun to play. Having a computer science degree has been really helpful in knowing an engine's limitations, how a computer works, and of course, being able to speak to programmers."

—SUSAN KARLIN

reflections

BY ROBERT W. LUCKY

JAMES STEINBERG

Visual Ubiquity

IN THE 1990s, when webcams first hit the market, I made up some special slides (yes, 35-mm slides!) to illustrate a story I used in several speeches.

I began the story by asking a question that has always mystified me: What did my dog do when I wasn't home? Well, I said, I could install a webcam in the hall and watch. But then maybe I should tie the webcam to the dog's head so I could follow his field of view. In my presentation, I would then show a charming picture of my dog with the webcam attached to his head. Everyone would laugh.

Even better, I'd say, let's pass a law that all dogs have to have GPS-enabled webcams. Then when anything interesting was happening in the world, you'd need only tune in to the nearest dog to watch. I'd then show another picture, this time of heads of state at a summit meeting, with my dog off to the side wearing his webcam.

Well, nearly two decades have passed, and we don't need dogs now—we have people with smartphones. And people are everywhere. We've come a long way since some students at the University of Cambridge installed what we would now call a webcam in their coffee room. For a while back then, such public webcams were a fascination. I don't think they are especially popular now—there is too much to do to watch nothing happening somewhere else.

But when something does happen, all those cameras constitute an evolving capability that we have yet to fully exploit or even understand. Unlike my proposed cam-enabled dogs, people choose their pictures and videos. For better and for worse, we can far outdo my imaginary dogcams.

Several billion people with cellphones are moving around in a world characterized by an evolving visual ubiquity that also includes increasingly dense real-time closed-circuit TV surveillance, satellite imagery, and street-view photography. It's amazing how quickly all this has happened. It seems only a few years ago that our main visual connection to faraway places was *National Geographic* magazine.

A hint of what we can do with all this imagery was seen in the recent DARPA Network Challenge. Ten red weather balloons were moored at various random places within the continental United States. A US $40 000 prize would go to the first competitor to locate all the balloons. Amazingly, it took a team from MIT less than 9 hours. This feat seems extraordinary when you consider that there are about 10 million square kilometers in the country. The MIT group solved two problems: how to encourage a lot of people to help, and how to filter all the input.

Another example is in the work of the organization Ushahidi, which uses crowdsourcing to aid humanitarian efforts. Following the devastating 2010 earthquake in Haiti, Ushahidi began an open-source project to develop an accurate crisis map of the country by compiling and integrating real-time reports from volunteers in local neighborhoods. Their contributions to the humanitarian efforts were remarkable and could not have been obtained otherwise.

There are ongoing technological developments that can augment this visual ubiquity. Face recognition, and the ability to track individuals through crowds and across multiple cameras, as in airport security, need algorithmic development to be more real-time and less labor intensive. There are also efforts to stitch together the billions of amateur photos on the Web to create a worldwide panorama.

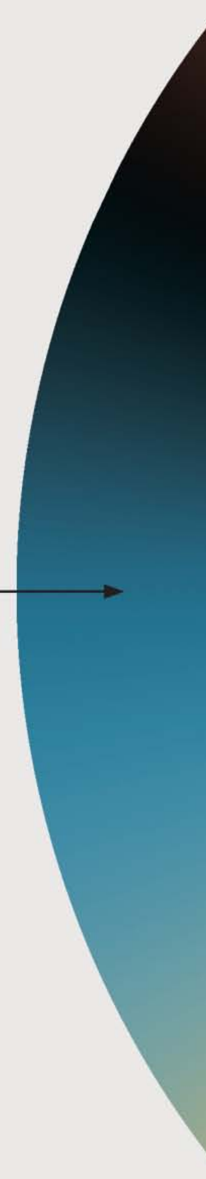
After all these years, I still don't have a home webcam. I'd like to, but I don't know what to do with it. I could point it at my driveway, which stretches westward for some distance through trees, but frankly nothing ever happens there—just like on most of the planet, I imagine. Maybe once a year my camera might see the glint of a deer's eyes. I know that there are companies that offer cloud-based services to filter out all the nothingness using change-detection algorithms, but I fear I'd be left with only an annual summary that says—to borrow a literary phrase—"all quiet on the western front." But then, you never know. And maybe my dog does something interesting while I'm gone, too. ❑

ieee spectrum | Previous Page | Contents | Zoom in | Zoom out | Front Cover | Search Issue | Next Page | Qmags THE WORLD'S NEWSSTAND®

SPECIAL REPORT

TOP TECH 2012

14 STORIES YOU MUST READ NOW



PREDICT THE NEXT CENTURY and you can fantasize; predict the coming decade and you can wax enthusiastic. But if you're looking at just the next 12 months, you'd better keep your feet on the ground. That's what we've done in this year's tech survey: In choosing our subjects, we considered mainly the likelihood of their figuring prominently in the coming year's tech headlines, not whether we thought—or hoped—the technologies themselves would succeed.

A case in point is extreme ultraviolet (EUV) lithography: It has been promoted for more than 15 years as the best way to sustain Moore's Law, and this is the year it's expected to reach the make-or-break point. We can't tell you whether it will win or lose, but in either case, the result will be big news in Silicon Valley—and beyond. *—Philip E. Ross & Samuel K. Moore*

ILLUSTRATIONS: CARL DeTORRES

ieee spectrum | Previous Page | Contents | Zoom in | Zoom out | Front Cover | Search Issue | Next Page | Qmags THE WORLD'S NEWSSTAND®

TOP TECH 2012

Good-bye, Wheelchair

This year an exoskeleton for paraplegics hits the market

by Eliza Strickland

In a warehouse that looks like a cross between a mad inventor's garage and a climbing gym, a pair of mechanical legs hangs from the ceiling on ropes. With the quiet whir of four motors, one in each hip and knee, the legs take a step, then another and another. This is an exoskeleton walking suit, and it is taking the hundreds of thousands of steps that regulators demand to prove that it's no mere toy but a reliable medical device, one that just might change the lives of people who thought they'd never again rise from a wheelchair. ■ The Berkeley, Calif., warehouse is the home of Ekso Bionics (formerly known as Berkeley Bionics), a young company that's about to step out onto the world stage. Early this year the company will begin selling its Ekso suit to rehab clinics in the United States and Europe, to allow patients with spinal cord injuries to train with the device under a doctor's supervision. By the middle of 2012, the company plans to have a model for at-home physical therapy.

When you don the Ekso, you are essentially strapping yourself to a sophisticated robot. It supports its own 20-kilogram weight via the skeletal legs and footrests and takes care of the calculations needed for each step. Your job is to balance your upper body, shifting your weight as you plant a walking stick on the right; your physical therapist will then use a remote control to signal the left leg to step forward. In a later model the walking sticks will have motion sensors that communicate with the legs, allowing the user to take complete control.

"We took the idea of the external skeleton, and we added nerves in the form of sensors and motors that represent your muscles and computers that represent your brain," says Eythor Bender, CEO of Ekso Bionics.

The company began its evolution in 2005 with the ExoHiker, an exoskeleton that allows able-bodied people to carry 90 kg (about 200 pounds) with minimal exertion. The company's engineers at first thought it would take 5 kilowatts to power such an exoskeleton, which would have meant bulky batteries and motors.

The breakthrough was a redistribution of weight that reduced the power requirements by three orders of magnitude. A later system, the load-carrying HULC (Human Universal Load Carrier), was licensed to Lockheed Martin Corp. for military development in 2009, and Ekso Bionics' engineers began looking for a new direction. Their energy-efficient devices, they realized, left them with a "power budget" that could be spent on moving the user's legs. That's when paraplegic people became the company's target customers.

A few other companies around the world are bringing out exoskeletons for people with disabilities, but Ekso Bionics' push in 2012 may give it a market advantage. Ten top U.S. rehab clinics have already signed up for the first batch of production units.

One of the first devices will go to Mount Sinai Hospital, in New York City, where Kristjan T. Ragnarsson, chairman of the department of rehabilitation medicine, has treated spinal cord patients for 40 years. His patients' priorities have never changed. "The first thing they want to know is whether they will walk again," says Ragnarsson. "As their physician, I always have to address that question."

Over the years he has told his patients about the latest inventions, from stiff air-

GABRIELA HASBUN

HELLO, EKSO
User Tamara Mena, who was paralyzed in 2005, gleefully puts her exoskeleton walking suit through its paces.

filled garments to devices that electrically stimulate the muscles, but all these contraptions proved too difficult for the patients to operate. "They were completely exhausted after just a few steps," he says.

Ragnarsson thinks the Ekso can succeed where so many others failed, because the powered device does most of the labor for the patient. "I'm optimistic, actually, that this will work," he says. "I think my patients will be able to stand up and take a few steps and face the next person directly on!"

In a rehab room at Mount Sinai Hospital in November, Robert Woo, an architect, is justifying his doctor's optimism. His high-tech wheelchair, which his kids have plastered with stickers, sits in the corner. That wheelchair has been his only source of mobility in the four years since a construction crane dropped 6 metric tons of metal on his job-site trailer, crushing his spine.

But today Woo stands tall. He leans forward on the two walking sticks as physical therapists and Ekso technicians buzz around him. Standing in the Ekso feels like floating, Woo explains, and he's still getting used to it. "I'm always looking down, wondering, How are my feet doing?" he says with a smile. "I have to build up confidence in myself and confidence in the device." Then a therapist calls out, "Step!" and punches a button on her controller. With the creak of plastic joints and the whir of motors, Woo is walking.

His progress is slow and jerky, and on one step he leans too far forward and starts to lose his balance before the therapists grab his arms and steady him. But most of the 308 steps Woo takes during the hour-long session are remarkably fluid, with a heel-to-toe gait. Achieving that natural stride was a major technological challenge, as it requires a sophisticated transition of control among the four servomotors that supply the torque to the knee and hip joints.

The session was only Woo's third time using the device, but he had already graduated from a wheeled walker to the walking sticks. He'll have to wait a bit before he makes any more progress: The Ekso was at Mount Sinai for only a week's tryout. Ragnarsson expects the hospital to buy a device of its own this year for the steep price of about US $100 000; that price should fall as production increases.

The company expects to test its physical therapy model soon on patients with other diagnoses, like multiple sclerosis and stroke. And by 2014, it plans to release a personal model that can be used not just for rehab but for everyday living. Woo says he looks forward to a day when he can stand in the Ekso and cook dinner in his kitchen or take a walk in the park with his children.

Before that day comes, though, Ekso Bionics must get approval from the U.S. Food and Drug Administration by proving both the device's safety and its benefits. And its engineers must work out how the user will initiate more complicated movements, like climbing stairs and sitting down.

Bender, Ekso Bionics' CEO, is confident that controlling Eksos will come to feel utterly natural for the people who rely on them for mobility. "People talk about robots taking over, especially in factories, and taking away our jobs. But the way we see it is, if you can't beat them, join them!" says Bender. "We are joining with the robots. And this has the ability to make us stronger, more productive, and to improve our quality of life." ❑

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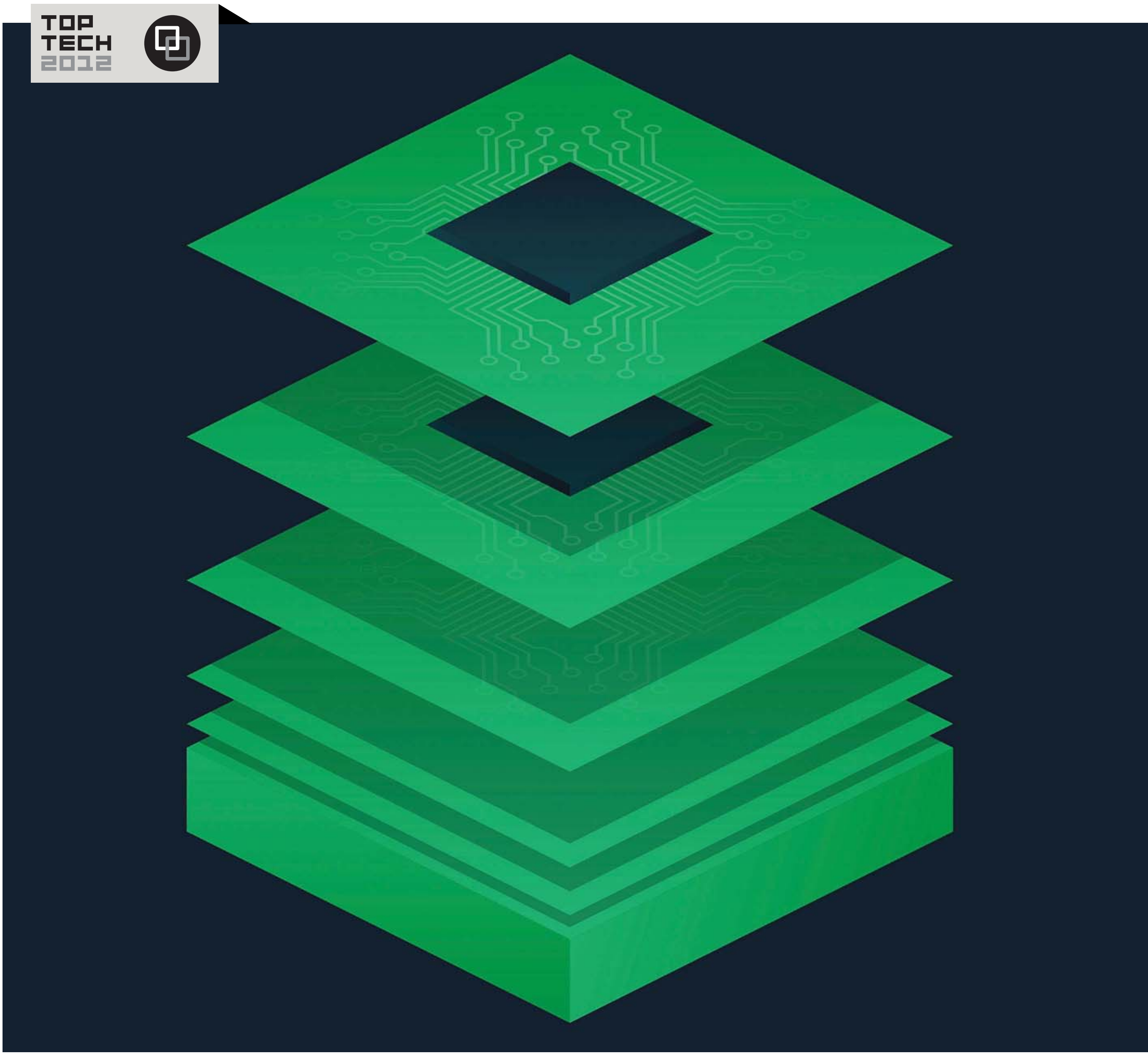
STEPPING OUT
At Mount Sinai Hospital, in New York City, Robert Woo uses the Ekso to walk again.

CATHY CLARKE/MOUNT SINAI MEDICAL CENTER

TOP TECH 2012



ICs GROW UP

In 2012, 3-D chips will help extend Moore's Law—and move beyond it

BY RACHEL COURTLAND

The integrated circuit could use a lift. Almost 50 years after Gordon Moore forecast the path toward faster, cheaper chips, we've miniaturized electronic components so much that we're increasingly colliding with fundamental physical limitations. The days of simple transistor scaling are long behind us—the latest, greatest chips are a hodgepodge of materials and design tweaks. These chips also leak a lot of power, and they contain transistors that are so variable in quality they're difficult to run as intended.

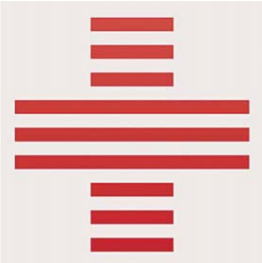
Fortunately, chipmakers are pursuing a pair of innovations that will give dramatic boosts in the two categories that really count: performance and power consumption. In both cases, the trick will be to build up and into the third dimension. And manufacturers will do it at the level of both the individual transistor and the full microchip. In 2012, the chip will start to become the cube.

PAUL TEBBOTT

TOP TECH 2012

Elementary, My Dear *Doctor* Watson

2012 TECH WATCH



IBM's answer machine, Watson, which won fame by beating champions of the television game show "Jeopardy," is studying medicine at Columbia University and the University of Maryland. The resulting diagnostic and therapeutic tool, which presumably will be put under the supervision of licensed M.D.'s, should hit the market late this year.

Until recently, microprocessor transistors have been flat, built into the plane of the silicon. Each field-effect transistor on a chip contains four parts: a source, a drain, a channel that connects them, and a gate on top that controls the current flow through the channel. Only the gate and a thin layer of insulator beneath it sit above the silicon.

But this past May, Intel unveiled its plans for the first big move away from the planar transistor. After months of gearing up production, the new transistors, which are built into a processor code-named Ivy Bridge, will make their way onto the market during the first half of 2012.

The switch to these pop-up transistors—often called FinFETs—helps tamp down one of the key problems that have emerged as engineers have shrunk transistor dimensions: leakage current. The smaller a transistor, the weaker the gate's control and the easier it is for current to sneak across the channel when the transistor is supposed to be off. Intel decided to go with a design that turns the transistor channel on its side, creating a protruding fin between the source and drain that can be controlled by a gate on three sides instead of one.

Expanding into the third dimension will let chipmakers continue shrinking transistors to boost speed, without leaking power. Indeed, Intel estimates the 22-nanometer Ivy Bridge chips will be 37 percent faster at low voltage and draw less than half the power of the company's 32-nm chips.

Intel's 3-D leap was anticipated, but its timing still came as a surprise. "Moving the technology from the lab to the fab is a big deal," says Tom Halfhill, a senior analyst at the Linley Group, in Mountain View, Calif. Based on available road maps, Halfhill says, other chipmakers working on FinFETs are a good four to five years behind Intel. "As far as we know, nobody else is close to volume production," he says.

Intel's FinFET isn't the only foray out of Flatland. In 2012 there will be solid progress on an even more promising trick: stacking chips and wiring them together with interconnects that run straight down the stack, like elevator shafts in a skyscraper. If all goes well, this reworked interconnect technology could yield vastly faster and more efficient devices, no matter how chunky their transistors might be.

In some ways, 3-D is nothing new to chipmakers. Flash memory, for example, is stacked to cut down on volume and boost speed. But chip stacking has been limited by wiring problems. Today's interconnects don't run through the silicon itself but instead go millimeters around it, impeding speedy signaling and sapping power along the way. Horizontal real estate is also precious. The thinnest interconnects are still 25 micrometers wide, and they must be packed along the edges of a chip, putting strict limits on how many input/output connections any one chip can handle.

Thus the attractiveness of going vertical, connecting one chip to another with copper lines that go straight through the silicon. If chipmakers can cheaply manufacture these through-silicon vias (TSVs), they can pack many more connections side by side using much slimmer wires. Going through chips instead of around the side will also reduce the length of interconnects from millimeters to 50 µm or even less—as thin as individual wafers can be made. The potential advantages are huge. Samsung, one of several companies working on making dynamic RAM memory stacks connected by TSVs, has estimated that the switch to vertical interconnects will cut power consumption in half, increase bandwidth by a factor of eight, and shrink memory stacks by some 35 percent.

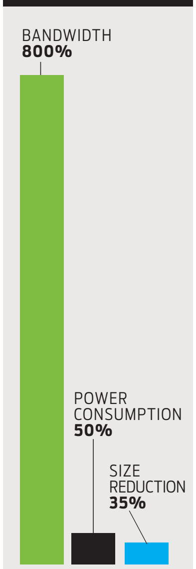
"It's really phenomenal that you can do something like that," says Sitaram Arkalgud, who directs the 3-D interconnect program at Sematech, a semiconductor industry consortium. "It's not often that you see this kind of a revolution come along."

To build TSVs, a wafer maker has to etch deep, narrow holes into a silicon wafer and then fill them with a nearly flawless layer of insulating material and then copper. But as a wafer heats up, copper expands at more than five times the rate that silicon does, exerting stress that can crack the wafer and render it useless.

Shepherding these wafers through the chip manufacturing process is also a challenge. Each wafer must be thinned to roughly 50 µm, less than the thickness of a human hair. Wafers that thin can curl up like pencil shavings. To work with them, chipmakers have to temporarily attach them to plates that can stabilize them during processing.

But industry watchers say that most of the main technical hurdles have now been overcome. This year, companies will be working out ways to introduce TSVs

Projected improvement to DRAM of 3-D interconnections



SOURCE: SAMSUNG

PAUL TEBBOTT

7 BILLION

Transistors in a four-chip device linked using through-silicon vias

without adding significantly to the cost of making a chip. This is "the year we figure out how to make them manufacturable. It's the year of process development and yield improvement," says industry consultant E. Jan Vardaman, president of TechSearch International, in Austin, Texas.

In fact, the most dramatic achievement in the coming year might be a simple stacking configuration that's often called 2.5D. This approach takes advantage of TSVs by running them through an intermediate layer of silicon called an interposer, which sits between an IC and a PC board. By one measure, the technology is more or less two-dimensional. All the packages you choose to put in a device—RF receivers, graphics units, memory, logic—still sit on the plane of the motherboard. But instead of copper traces running across the motherboard from package to package, in this configuration copper connections run through TSVs and past the interposer layer, where the vertical wiring is connected in a series of horizontal patterned layers. By moving all the connections outside the plane, device makers can place chips right next to one another, saving space and power.

One of the pioneers of interposer technology is Xilinx, in San Jose, Calif., which has used TSVs to wire together four field-programmable gate arrays to form the world's largest FPGA. This programmable pachyderm contains nearly 7 billion transistors, easily 50 percent more than the biggest single FPGA, Xilinx says. The firm estimates that the device consumes less than a fifth of the power that would be needed to operate a comparable set of individually packaged FPGAs strung together with traditional copper interconnects.

Vertical stacks of TSV-enabled chips are not far behind 2.5D technology. Elpida, Micron, Samsung, and Toshiba are all in various stages of creating memory stacks built with TSVs. Some of these companies have already shipped prototype chips to customers, and industry watchers expect TSV-based high-end memory—the sort that would be useful for servers and high-performance computers—to emerge in 2012.

"We'll see [TSVs] start to come out in applications where cost is not the main concern but performance is," says Jim Walker, a vice president of research at Gartner who follows packaging developments.

Memory chips are a natural entry point for new 3-D technology because they are more tolerant of thermal stress, Walker says. Chipmakers, he says, still haven't found a good way to carry heat out of the middle of a stack. The problem is particularly thorny when the stacks contain different chips. "The graphics chip is like an oven," Walker says. "If you're putting memory or RF die on top of it, you'll have different heat generators with different thermal expansion rates." The result is degraded chips that don't run as well or as long as they should.

There are other big questions that will need to be addressed as manufacturers contemplate making more complicated chip stacks. How do you make sure that two chips made by different companies can be connected? Is there an inexpensive way to verify that each layer in a package works? And if the finished IC doesn't work, how do you determine who is responsible for the failure?

Foundry giant Taiwan Semiconductor Manufacturing Co. (TSMC) has been struggling with this last question as the company tries to ramp up interposer production by its target date in the second half of 2012. "When we started TSV development, we did it the conventional way," says Doug Chen-Hua Yu, who heads up interconnect and packaging R&D at the company.

Yu says TSMC typically sends completed wafers to be packaged by assembly companies known as OSATs (outsourced subassembly and test providers). But the thinned wafers are too easily damaged. When that happens, "it's very hard to go back and decide who did what wrong," Yu says. "It [could be] the wafer fab or the OSAT or FedEx. We don't know."

Even if wafers are inspected carefully before and after shipping, there could be latent damage that emerges only after processing. As a result, Yu says, TSMC is now hoping to do most of its TSV wafer manufacturing and packaging in-house.

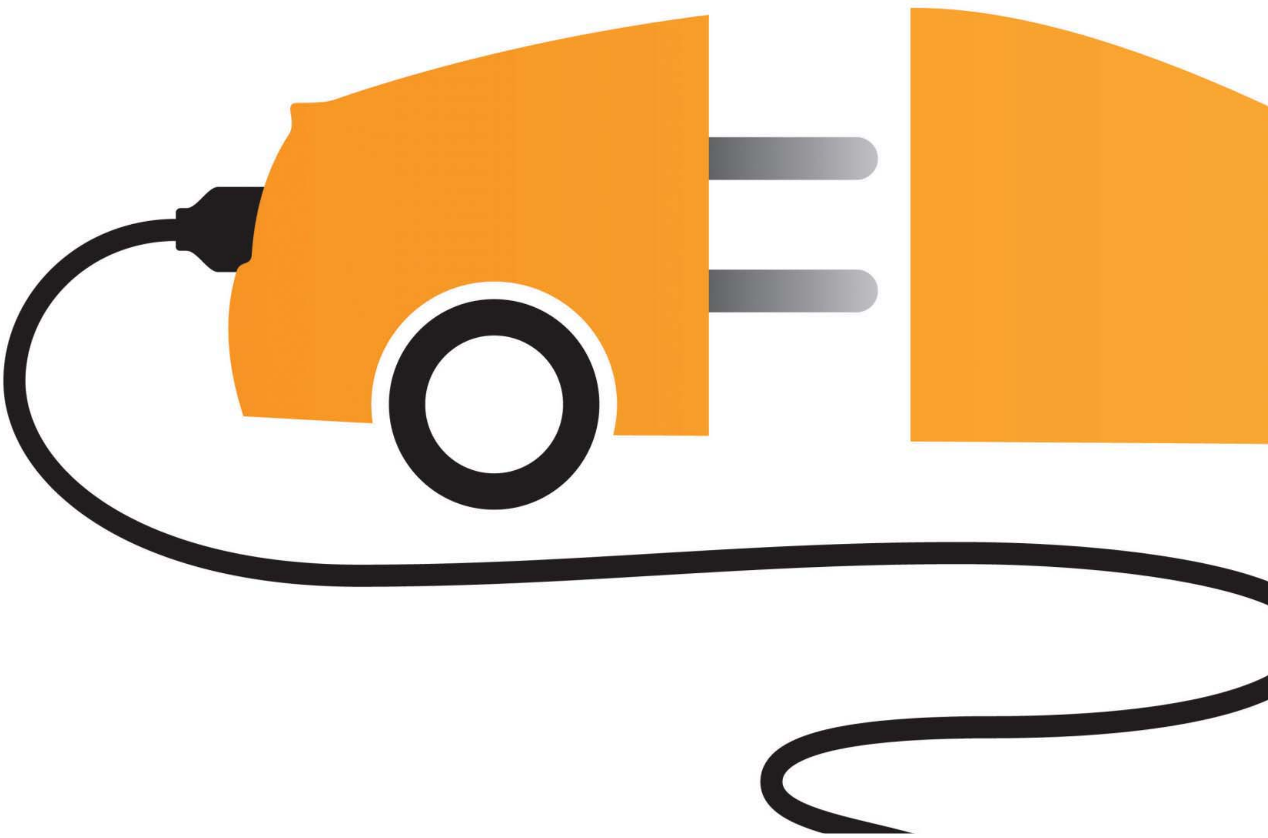
Liability issues, industry standards, and a host of other manufacturing matters still need to be sorted out. But no one seems to foresee any insurmountable hurdles to 3-D TSV technology. "It's changing how we do the whole supply chain. That's why it's taking such a long time to get this on the ground and running," says Sematech's Arkalgud. "But once it happens, it will be going for quite some time." ❏

Phones That Flex

2012 TECH WATCH

PAUL TEBBOTT

Touch screens might soon seem passé. In November, Nokia showed off a prototype smartphone that's literally more flexible: It lets you navigate applications by twisting and bending it. Reports vary on whether the real product will be out before 2013. We wonder what combination of contortions will let you make a call.



TOP TECH 2012

Plug-ins Proliferate

In 2012, plug-in cars will start to seem normal

by David Schneider

Do you own a plug-in car? Do you even know anybody who does? Probably not. But that might very well change this year. Electric cars aren't new, of course. Mitsubishi's all-electric i-MiEV has been available in several countries since 2010. The US $35 200 Nissan Leaf, another pure electric vehicle, has been selling in Japan and the United States for more than a year. The Chevy Volt is also available in America, as is the Tesla Roadster, a $109 000 toy for the rich.

And yet, despite the intense press coverage and feverish anticipation, relatively few of these cars have found their way into garages and driveways. In 2012, however, a big influx of plug-in cars will help these vehicles start shedding their novelty image and in some places may even justify the construction of public charging stations [see "State of Charge," in this issue].

By the end of 2012, for example, Toyota will introduce no fewer than three new plug-in models, and Ford and Volvo will both have their first-ever plug-in electrics in showrooms. Nissan and General Motors will ramp up production of the Leaf and the Volt as well. Nissan aims to produce about 4000 Leafs per month at its plant in Oppama, Japan.

ILLUSTRATION BY PAUL TEBBOTT

Capacity will rise by another 150 000 cars annually when modifications to Nissan's assembly plant in Smyrna, Tenn., are completed later this year, the company says. And Nissan projects that further production increases in 2013 will bring the total to about a quarter million cars a year, which is on par with the number of Volkswagens of all types sold in the United States. If Nissan achieves that kind of volume, the Leaf will have truly broken out of its niche, becoming the Prius of pure electrics.

Chevy's Volt, which costs a little more than $39 000, will also be seen in far greater numbers. Production of the Volt, which last year totaled about 5000 cars, is slated to rise to 60 000 in 2012, with some being sold outside North America.

Even Tesla is trying to go mainstream. This past October, the California carmaker showcased beta versions of an all-electric sedan, the Model S. At $57 400, it ain't cheap, but it's much less pricey than the Roadster.

To scale up its operations, Tesla acquired the New United Motor Manufacturing plant, in Fremont, Calif., where General Motors and Toyota formerly built cars. Tesla projects that later this year, Model S vehicles will be made there at a rate of 20 000 per year.

Much of the money to buy that factory and get it tooled up came from the initial public offering of Tesla stock, which raised $226 million for the company in June of 2010. Just weeks before the IPO, Tesla and Toyota agreed to collaborate on the development of electric vehicles. The two companies began by working on an all-electric version of Toyota's RAV4, an SUV. Commercial versions of that vehicle will be produced later this year alongside conventional RAV4s at Toyota's assembly plant in Woodstock, Ont., Canada.

This is not the first time the RAV4 has been electrified. Between 1997 and 2003, Toyota produced an earlier battery-powered version of this car, some 1500 of which were sold or leased in California. The later ones included a 27-kilowatt-hour nickel metal hydride battery pack, which provided a range of approximately 160 kilometers.

The electric RAV4 design that Toyota and Tesla have worked out will have a similar range but much better acceleration and top speed. That's because it will incorporate Tesla-made drivetrains, including the same kind of battery modules found in the Roadster and the Model S. These modules are unique among electric cars in that they contain thousands of thumb-size lithium-ion cells—the kind you might find inside your laptop.

Although other car manufacturers are now also using lithium-ion batteries to power their plug-in vehicles, they construct battery packs using a smaller number of large-format cells. The Leaf's 24-kWh battery, for example, is composed of 192 cells. And the electric version of the Ford Focus, which debuts this year, uses a 23-kWh pack of just 98 cells.

Toyota's decision to use Tesla's many-thousand-cell battery modules for its electric RAV4 is a puzzle. Toyota will be selling two other plug-in vehicles in 2012—an all-electric version of the diminutive Scion iQ and a plug-in version of the company's well-known Prius hybrid—and their battery packs will have the more standard configuration. Why go with something so different for the new RAV4 EV?

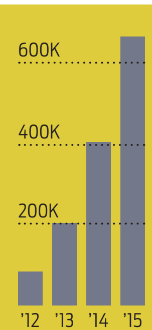
Sheldon Brown, executive program manager at the Toyota Technical Center in Saline, Mich., explains the reason for the dueling battery technologies. "We see this as an opportunity to challenge our current way of thinking and to reevaluate our own development processes, ensuring that we are not complacent," he says.

You can make a strong case that the likeliest to succeed is the plug-in Prius, which will go on sale in Europe, Japan, and the United States early this year for $32 000. The reason? It breaks from established technology *the least*.

The car is essentially a clone of the company's third-generation Prius hybrid. But in place of the latter's 1.3-kWh nickel metal hydride battery, the plug-in model contains a 4.4-kWh lithium-ion battery. This battery can propel the car for about 24 km without help from the car's gasoline engine. That limited electric range leaves some plug-in proponents underwhelmed—the Chevy Volt, by contrast, squeezes about 60 km from its battery.

But Mike Ferry, transportation program manager at the California Center for Sustainable Energy, in San Diego, likes the new Prius. He and his coworkers took part in the demonstration and testing program Toyota mounted last year using preproduction versions of this car. Ferry let many of his colleagues use these plug-ins to see how they'd fare. "We have people who live 6 or 7 miles away—all urban driving. They were able to go all week without the gas engine coming on," he says. Most couldn't do that, but on average, his group burned less than 3 liters per 100 km (between 80 and 85 miles per gallon), almost doubling the efficiency of the fuel-sipping regular Prius.

Toyota expects to be able to produce 50 000 plug-in Prius cars annually. While that's a modest number compared with sales of the conventional Prius, which exceed 400 000 cars a year, it's yet another sign that plug-in vehicles are finally going places. ❏



Plug-in EV Sales, U.S.

The number of plug-in cars on U.S. roads is expected to rise sharply over the next few years—though not sharply enough to meet President Obama's stated goal of 1 million by 2015.

Source: Pike Research

TOP TECH 2012

WIN-WIN?
Microsoft's Steven Sinofsky gives attendees an early look at Windows 8 at a September conference.

A REDO FROM REDMOND?

The 2012 release of Windows 8 will show whether Microsoft can surf the tablet tidal wave

BY STEVEN CHERRY

The first time Microsoft was caught off guard, Bill Gates managed to turn things around by sending the entire company his famous e-mail, "The Internet Tidal Wave." The current challenge—the drift away from PCs in favor of mobile devices—may well be greater.

The move began in 2007, with the introduction of Apple's iPhone, and it was kicked into high gear with the advent of the iPad in 2010 and an Android equivalent in 2011. Suddenly, Microsoft's business was based on yesterday's platforms.

"Their products are fine on notebooks. But on phones and tablets, they're in bad shape," says Michael Silver, an analyst at Gartner, a technology research firm.

Yesterday's platforms are coming to be represented by an ever-narrowing slice of the computing pie. Last year people bought twice as many smartphones as notebooks, and tablets are also set to exceed notebooks by 2016, according to Gartner. Microsoft's quick solution to its mobile-computing problem was Windows Phone 7, but in the third quarter of 2012 the company is expected to launch its more considered answer: Windows 8. The future of the company may depend on it.

"Windows 8 has to be really good," says Michael Cherry, lead analyst for operating systems at Directions on Microsoft, in Kirkland, Wash. (and no relation to the author). "They can't have another Vista," the ill-regarded system that preceded Windows 7. "Especially when you're late to market, you have to leapfrog," he says.

The early indications—which mainly come from a prebeta version of the software that Microsoft handed out at its Build conference, in September—are mixed.

"They have a lot of work ahead of them," Cherry says. "The version they gave out at Build is good for developers, to give them some idea of the changes, to test programs, and so on. But performance is very slow. And they only had code for Intel processors, not ARM." That last point may be critical: Today's smartphones and tablets all use ARM-based microprocessors.

Microsoft's hardest task might be the interface, says Cherry. "It's going to have to do what no operating system has yet done: seamlessly bridge the divide between smartphones and PCs."

James Ashley, a design architect at the Web-development firm Razorfish, in Seattle, thinks Microsoft may have met the challenge. Indeed, he says he was "blown away" by what he saw of Windows 8 at Build. There, Microsoft showed a tablet in a docking station that also had an external desktop monitor. The user can touch the tablet's screen or use a keyboard and mouse to work the external screen.

"They have what looks like two different operating systems side by side. And the part that took everybody by surprise was that you're switching back and forth between [them] casually," says Ashley. That kind of integration of the mobile and desktop experiences might be just the leapfrogging jump that Microsoft needs.

"A lot of people want to use a tablet in the office now," he says. "What Microsoft has done is push the story a little bit further—we can use a tablet with a docking station and a big screen, so we can have a traditional desktop experience, but at the same time we can just pull the tablet out and take it to a meeting, or home."

The greater threat to Microsoft might be Amazon. Its inexpensive Android-based Kindle Fire, and the ecosystem of movies, books, music, apps, browsing, and shopping that surrounds it, may tempt an unexpectedly large number of consumers away from the PC entirely. Says Cherry, "What if people say, 'Gee, instead of a new laptop, we'll get three Kindles and everyone can have one'? That might be something that no amount of PC-tablet-smartphone integration can overcome." ❏

ALEX GALLARDO/REUTERS

ieee spectrum Previous Page | Contents | Zoom in | Zoom out | Front Cover | Search Issue | Next Page

TOP TECH 2012

LEDs FOR LESS

In 2012, there will finally be a first-rate LED bulb you can afford

BY RICHARD STEVENSON

BRILLIANT IDEA
The Philips L Prize–winning LED bulb draws one-sixth the power of an incandescent and lasts at least 25 times as long.

PHILIPS

The passing of Edison's bulb has already been decreed, and which of the two alternatives will replace it is at last becoming clear. It will be the LED.

The success of the light-emitting diode means curtains for the compact fluorescent light (CFL). This clunky, mercury-ridden, hard-to-dim, excessively white device has just two things going for it: It's more efficient than Edison's bulb and, right now, cheaper than the LED-based alternative.

But the LED's quality is rising and its price is dropping—fast. Even now you can pick up a 40-watt-equivalent LED bulb with an appealingly warm hue for just US $9.97. By the end of 2012, a 60-W cousin could be available for about the same price, and within a few years for much less than that.

A glimpse of what's to come appeared this past August, when an LED lightbulb from Philips Lighting North America won the U.S. Department of Energy's $10 million Bright Tomorrow Lighting Prize, better known as the L Prize.

"Our L Prize bulb is essentially the Ferrari of lighting," boasts Todd Manegold, director of LED lamps marketing at Philips. "It does everything that any lightbulb could ever or should ever want to do."

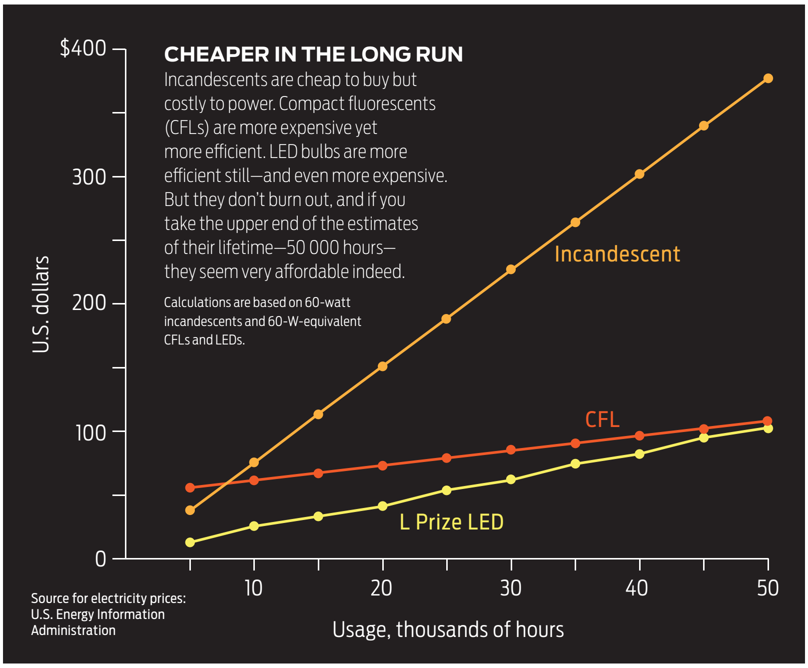
In the beginning—perhaps in the first half of this year—the bulb will sell at a Ferrari price, perhaps $50 apiece. But the pressure to cut that premium will grow as early adopters buy up other brands of LED bulbs that trade efficiency for lower prices. And indeed, those prices are falling fast.

Philips had to design the bulb to hit a slew of engineering targets set by the DOE. First, the bulb had to put out at least 900 lumens—as much light as a 60-W incandescent bulb, the most common kind in the United States. Then it had to last for 25 000 hours, which is roughly 25 times as long as a standard incandescent. And it had to draw less than 10 W.

Philips built its bulb around the Luxeon Rebel, an LED radically different from those that backlit the keypads and displays of early handsets. In a conventional LED, most of the light bounces around within a stack of semiconductor layers, which have a far higher refractive index than air, so only a small proportion of the light goes out in the proper direction. In the Luxeon Rebel, a metallic mirror on the bottom of the chip keeps light from leaking out the wrong way, and the roughening of the top surface allows more of the properly directed light out of the box. As a result, the bulb needs just 9.7 W to yield 910 lumens, whereas an incandescent's 60 W yields only 800 lumens.

The L Prize bulb also features omnidirectional emission, a hallmark of the incandescent bulb. Simply putting a handful of white LEDs into a glass bulb will not lead to uniform illumination, because each device produces a beam. It would be like trying to illuminate a room with a dozen flashlights.

The problem comes down to how white LEDs are constructed. Traditionally, white LEDs are made by applying a yellow phosphor to a blue-emitting chip of gallium nitride and indium gallium nitride. That way, the mixing of the yellow emitted by the phosphor and the blue that passes through it combine to create white light, but only from the coated face of the chip. Philips gets around this problem by putting the phosphor close to the outside of the bulb and illuminating it fairly evenly with a battalion of 18 LEDs. "When their light hits the phosphors, it is diffused into a



pattern that gives you a clean, uniform look," explains Manegold.

The resulting glow is reasonably similar to what you'd get from an incandescent bulb. Says Manegold: "In our headquarters for lamps, we put an LED like the L Prize, an incandescent, a halogen, and a CFL behind lamp shades and make people play the guessing game." During the past few months he has played this game with many guests, and none of them could tell the difference between the LED bulb and the incandescent.

Philips's bulb also had to work well when shaken about and subjected to temperature extremes, high levels of humidity, and distortions in supply voltage. "We compared [them] to CFL lamps—the better quality ones. All the LEDs made it through, and none of the CFLs made it through," says James Brodrick, solid-state lighting program manager at the DOE.

So if you can't afford the very best LED bulb, what can you expect from the cheaper products that are already out there? One option is Home Depot's EcoSmart range, which is made by the Lighting Science Group Corp. of Satellite Beach, Fla. For $9.97 you can pick up a 40-W equivalent, and by this summer there should be a 60-W version retailing for less than $15. What's more, Lighting Science Group says it will equal the efficiency of the Philips L Prize bulb.

By year's end you can expect a further drop in price. The powerful LEDs used for lighting will be 27 percent less expensive, says the United Kingdom–based market analysis firm IMS Research, and that drop in cost will make a big impact on the price of the bulb.

One reason why it's getting cheaper to make LED chips is that producers are migrating to larger wafers. However, the most important reason is simple economics: The LED market is awash with devices following a production ramp-up in China, which is making great efforts to cut energy consumption, says market analyst Ross Young of IMS Research.

US $2000
Cost of ridding a room of the mercury from a broken CFL

The Chinese government is offering a wide range of incentives to any firm willing to try its hand at manufacturing. Until recently these incentives included a subsidy covering up to three-quarters of the purchase price of the semiconductor fabrication tool needed to grow the nitride films that form the heart of LEDs, a multiwafer MOCVD (metal organic chemical vapor deposition) reactor. No wonder Chinese purchases of these tools have gone through the roof. In 2010 and 2011, shipments hit about 800, quadruple the number in previous years, and about 70 percent of the market.

Right now, though, most Chinese firms are just producing little glowworms for Christmas lights and the flashing heels of children's sneakers. These outfits have yet to master the "black art" of epitaxy and, in particular, to learn how to reduce the number of light-quenching defects in nitride films. These defects stem from the 16 percent difference in the spacing of atoms between the films and the sapphire substrates on which they are deposited. Only after these tricks are learned will the Chinese firms produce better material. After they do, they'll have to develop light-extracting LED architectures like that of the Luxeon Rebel to make devices bright enough for use in lightbulbs.

In the meantime, China's flooding of the low-end market with cheap, low-power LEDs is having an effect on the high end, according to Young. When the LED oversupply began, in the second half of 2010, it drove other LED makers out of their bread-and-butter market in display backlighting—and into general lighting. The domino effect has thus created a surplus in that market, too. China's efforts continue, and so the prices of all LEDs will fall throughout 2012.

Will this price decline immediately make the LED lightbulb a worthwhile purchase? The answer depends on what you're screwing into your sockets today. If you still use incandescents, switching to an LED bulb makes a lot of sense. That's because it costs about $180 to run a 60-W incandescent for 25 000 hours; in comparison, the electricity bill for an LED bulb producing the same amount of light is between $25 and $50. Besides, that 25 000 hours of lighting will require 25 incandescents as opposed to just one LED bulb.

However, if you now use CFLs—as is the case in most of Europe—it will be harder to decide whether 2012 is the time to switch to LEDs. CFLs are still much cheaper than LED bulbs, and this easily makes up for their 10 000-hour lifetime.

In any case, this year you will for the first time be able to afford an LED bulb that's clearly superior to a CFL. It will give off a nice warm glow, work with your dimmer switch, use energy frugally and when you finally replace it after 15 years, you can just throw it in the dustbin.

By then, you'll struggle to recollect what the letters "CFL" ever stood for. ❏

TOP TECH 2012

FUTURE VISION

In 2012, electrodes will bring eyesight to the blind

BY ELIZA STRICKLAND

SEEING THE SIGHTS
Barbara Campbell's retinal prosthesis sends 30 images per second to her optic nerve.

DAVID YELLEN

When light hits Barbara Campbell's eyes, it triggers no response in her retinas, and no signals flash up her optic nerves to her brain. A genetic disease killed off her retinas' photoreceptor cells, leaving her completely blind by her 30s. But where her body failed her, technology rescued her. In 2009, at the age of 56, Campbell had an array of electrodes implanted in each eye, and she now makes her way through the world more confidently, aided by bionic vision.

Her sight isn't fully restored, not by a long shot, but the darkness has been replaced with rough shapes and patterns of light and dark. "The building where I live has a large light at the entranceway outside," says Campbell, who lives in New York City. "I hadn't been able to see that light in 16 years. Now, when I'm walking down the block, I can look up and identify the building."

The devices in Campbell's eyes come from Second Sight Medical Products. After 13 years of product development, the company's Argus II Retinal Prosthesis System is now hitting the market. In 2011 the company won regulatory approval in Europe, and eye surgeons there are just beginning to perform the implants. This year the Los Angeles–based company hopes to get approval from the U.S. Food and Drug Administration as well. "I didn't think it would take this long," says CEO Robert Greenberg, "but it's finally real."

The process that allows the blind to see starts with a pair of sunglasses, which sport a tiny video camera mounted in the bridge just above the nose. The camera captures an image and sends it down a wire to a visual processing unit hanging on the patient's belt. That VPU—which is a little larger than a smartphone—converts the world's complexities into a 60-pixel image in black and white, which it sends back to transponders on the glasses. From there the image goes wirelessly to antennas wrapped around the sides of the eyeballs, and from there to the 60-electrode arrays that are tacked to the delicate retinas.

The Argus II system can't help all blind people, only those with degeneration of the retina's photoreceptor cells. The electrodes take the place of those damaged photoreceptors and stimulate the cells that are attached to the optic nerve. So far, Second Sight has concentrated on patients with retinitis pigmentosa—the disease Campbell has—but the company's device may also help with macular degeneration. Greenberg says that about 200 000 people in the United States and Europe could benefit from the implants.

Campbell was a volunteer in the second round of clinical trials. Her doctor, Lucian Del Priore, explains that patients need training to get the technology's full benefits. At first the medical team directly stimulates the electrodes. Says Del Priore: "We electronically project an image of a square onto the retina, and say, 'What does that look like?' And the patient says, 'It looks like an amoeba.'" The technicians have to compensate for differences in the distance between each electrode and the retina, Del Priore explains. "The distances have to be balanced, like balancing your stereo system."

Once the training and the balancing are done, however, patients gain a crude kind of vision—enough to make out doorways, the crosswalk on a street, the brightness of a face turned toward them. "We're not providing normal vision," says Greenberg. "We're providing cues and clues to help people navigate the world."

Second Sight's engineers are already thinking about their next move. Greenberg says a device with more electrodes (and thus more pixels) is likely, but adds that patients' vision can also be improved by using software tricks in the visual processing unit. The company is already experimenting with color vision.

"We've produced blues and oranges and yellows repeatedly," Greenberg says. "Blues seem to be the most emotionally rewarding. Almost universally, patients say, 'Please, show me that again.'" ❏

GIANNI TESSICINI/INAF-FGG

ieee spectrum Previous Page | Contents | Zoom in | Zoom out | Front Cover | Search Issue | Next Page

TOP TECH 2012

IN SEARCH OF ALIEN WORLDS

This year, a new exoplanet hunter will see first light
BY RACHEL COURTLAND

Francesco Pepe leans over a large black chest in the basement of the Geneva Observatory. He lifts the lid to reveal a length of rubbery fiber-optic cable coiled along the bottom and surrounded by steep cliffs of foam. "I think they may have gone a little overboard with the packaging," Pepe says.

Dwarfed by its container, the cable doesn't look that impressive, but it will soon be a key component in the hunt for planets like our own. In just a few months, astronomers will use the fiber to feed starlight into a new detector—the High Accuracy Radial velocity Planet Searcher–North (HARPS-N), an ultraprecise spectrograph that is being assembled nearby, not far from a field of grazing horses.

In the coming months, Pepe, an astronomer, and his colleagues will take apart the go-cart–size instrument, box up the pieces, and put them together again in a room near Italy's Telescopio Nazionale Galileo on La Palma, one of the Canary Islands.

When HARPS-N begins observations in April, astronomers expect it will be the most precise planet hunter in the northern hemisphere. They also reckon it will be particularly well placed to help bag the most coveted extrasolar quarry of all—planets small enough to have rocky surfaces and cool enough to have liquid water. The reason? HARPS-N will not be working alone. It will view a particular patch of the sky that has been the singular focus of NASA's Kepler telescope for almost three years.

NEW HORIZONS Italy's Telescopio Nazionale Galileo on La Palma, one of the Canary Islands, will host a new planet-finding instrument.

Kepler, which trails behind Earth in a solar orbit all its own, is on the hunt for the subtlest of flickers—periodic dips in stellar brightness caused by planets that pass, or "transit," in front of their host stars and briefly block about 0.01 percent of the light. And by all accounts, the spacecraft's dogged focus on a single region of the sky has paid off nicely. In December, Kepler's astronomers announced the discovery of a planet orbiting far enough from its sun-like host to be able to boast liquid water.

PRECISION WORK
Astronomer Francesco Pepe stands beside the partially assembled HARPS-N spectrograph.

With a little luck and enough time, Kepler will find many more such planets, some quite similar in size to Earth.

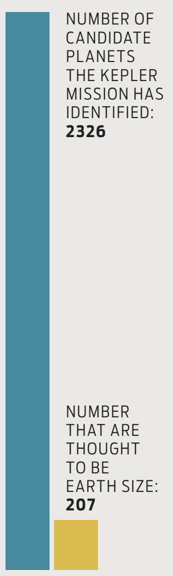
To confirm its discoveries and learn as much as possible about these planets, Kepler needs help on the ground. Unless the space telescope spots a close-knit system of planets that influence one another's orbits, Kepler's measurements can reveal only the size of a planet, not its density. To distinguish a gas giant like Neptune from a rocky super-Earth, astronomers need a tool capable of measuring mass precisely—a spectrograph.

A spectrograph uses a diffraction grating to separate incoming starlight so that different wavelengths hit different parts of a charge-coupled device (CCD). By a trick of inference, astronomers can use changes to surrounding pixels to pinpoint—with subpixel precision—the shift in any particular peak or trough in a star's spectrum. These shifts can occur if the star is moving toward or away from Earth. If a detector shows a star wiggling back and forth, and if these wiggles occur with regularity, the signal is a good indication that there is a planet in orbit, tugging on its host.

HARPS-N should be able to detect changes in the position of spectral lines to within 15 nanometers, which is about one-thousandth the width of a single pixel on its 6-centimeter-wide, 16-megapixel CCD. That's enough to pace the to-and-fro motion of a star to within 1 meter per second—about walking speed—from hundreds of light-years away.

Even that's not quite good enough to spot something like Earth from afar, says David Latham, a member of the HARPS-N team at the Harvard-Smithsonian Center for Astrophysics in Cambridge, Mass. But he says HARPS-N will still be more than twice as precise as the Kepler team's main follow-up instrument, the High Resolution Echelle Spectrometer, which sits atop Mauna Kea, Hawaii at the W.M. Keck Observatory.

As a result, HARPS-N and Kepler together will be able to offer portraits of planets that are on the edge of habitability. Chances are good, team members say, that HARPS-N will be able to see rocky planets that are roughly a few times the mass of Earth and on orbits that lie within the "Goldilocks" zone, where temperatures are just right for life. "We're not going all the way to characterizing true Earth twins, but we are pushing in that direction," says Latham, who helped to get the HARPS-N project started. "It's a big step."



SOURCE: NASA

The detector's main components are nearly identical to those of its progenitor, the HARPS detector at the European Southern Observatory's high-altitude La Silla Observatory, in Chile. But HARPS-N will also get a few improvements that could help boost its sensitivity.

The telescope's new fiber is one of the key changes. The original HARPS instrument uses a circular fiber to feed starlight into the spectrograph. But the position of the light that exits the fiber can shift depending on how a star is positioned in the telescope, and that can register as movement of spectral lines on the detector. "If [the lines] move because of differing illumination, that is catastrophic for us," Pepe says. To remedy the situation, HARPS-N will use a fiber with an octagonal cross section. The team hopes that the eight facets will scatter and homogenize the light so that it will always exit the fiber evenly.

A few months after installation, HARPS-N will play guinea pig for another potential improvement, a new kind of light source called a laser frequency comb, which could be used to calibrate the detector. Today many astronomical spectrographs are calibrated using the spectral lines emitted by thorium argon lamps, which have irregular lines that vary widely in brightness and spacing and shine on only a small fraction of the CCD cells in a detector. A laser comb instead uses brief pulses of laser light to create millions of evenly spaced lines over a wide range of wavelengths, which can be tuned to calibrate every pixel in a spectrograph's CCD. A comb calibrator can also be made very stable by matching key frequencies with those of an atomic clock. The HARPS-N team will test one incarnation of the laser comb, which uses a titanium sapphire laser, while others are working on fiber laser-based systems.

In the next few years, astronomers hope these combs could help improve the precision of stellar spectrographs by a factor of 10, if not more. If there are no confounding factors—not least the natural fluctuations in a star's atmosphere—that should be precise enough to detect the planet of our dreams: a true Earth twin. ❏

RACHEL COURTLAND

TOP TECH 2012

A BATTERY AS BIG AS THE GRID

2012 could mark the arrival of utility-scale battery storage

BY JEAN KUMAGAI

POWERHOUSE This lithium-ion battery installation can smooth out variability in the adjacent wind farm near Elkins, W.Va.

AES ENERGY STORAGE

Sometime this quarter, a shovel will sink into the dry desert soil of a Mexicali industrial park, breaking ground for the construction of an unprecedented energy-storage facility. Once completed, its batteries will be able to feed a full gigawatt into the grid for 4 to 6 hours.

By far the largest installation of its kind anywhere, it will help keep the lights on in Baja California and in the future, Southern California, just across the border. It should also improve the reliability of both the Mexican and U.S. grids and pave the way for using more solar and wind power. And with dozens of other battery-based energy-storage projects in the works elsewhere in the world, 2012 may be a turning point for the electricity industry—where up to now, adding new capacity has always meant building an expensive new power plant.

At press time, Jacob Rikard Nielsen, vice president of business development for Rubenius, the Dubai-based company behind the Mexicali project, said plans were still being finalized, including a timeline for the project and the type of batteries it would use. The work builds on two smaller energy-storage sites the company has installed in Abu Dhabi, which use sodium-sulfur batteries from the Japanese company NGK.

One of the chief drivers of the Mexicali project is California's goal of having 33 percent of its electricity come from renewable sources by 2020. "They're already seeing problems today in terms of grid stability and flexibility," Nielsen says.

Eric Wesoff, an industry analyst with Greentech Media, explains why: "A wind farm only works when the blades are spinning. It might have a nameplate capacity of 100 megawatts, but it never puts out that much. Sometimes it's 70; sometimes it's nothing. To a grid operator, that kind of resource is a headache rather than an aspirin." To compensate for solar and wind's fitfulness, utilities end up building more gas turbines.

Using a bank of batteries allows utilities to even out the supply of renewable electricity. "So now that 100-MW wind farm can say, We're a 40-MW, steady-state, 24/7 energy source—more like a coal plant," Wesoff says. "That's more valuable to society."

Utilities have long avoided batteries, because the technology was too expensive and not robust enough to last for tens of thousands of charging cycles. At present, the world's biggest grid-scale battery is a bank of nickel cadmium cells in Fairbanks, Alaska, which can produce up to 52 MW of emergency backup power for about 15 minutes.

Storm's A-Comin'

2012 TECH WATCH

This year the sun reaches its 11-year peak in activity, producing flares, mass ejections, and electromagnetic gusts that may snarl power grids, satellite communications, and GPS signals. Devotees of ancient wisdom say it's all in line with the Mayan prophecy of the end of the world. NASA pooh-poohs such prognostications.

Some electric utilities store energy by pumping water uphill and then recapture the stored energy by allowing the water to flow back downhill through turbines. Worldwide, pumped hydro facilities can produce about 127 gigawatts this way. Compressed air is also used as a storage medium, a strategy that yields just a few hundred megawatts in total, about as much as battery-based energy-storage facilities can now produce.

But thanks to investments made by the consumer-electronics and electric-vehicle industries, battery technology has advanced enormously in just the past decade. "Today you've got two or three batteries on your person at all times," notes Haresh Kamath, program manager for energy-storage research at the Electric Power Research Institute (EPRI). "The research applied to those industries is now being applied to batteries for the grid."

The potential market for grid-scale storage is substantial. Rubenius estimates it at US $30 billion per year, "plus or minus $5 billion," Nielsen says. "Of course, that's not going to materialize tomorrow. But as the technology matures and utilities gain experience, we'll get to that market status in the next 10 years. I'm quite optimistic."

However, a lot of work remains between now and then, Kamath notes. Although many companies are touting novel battery technologies for grid-scale storage, only a few have been tested in a utility setting. Another stumbling block is terminology. Utility equipment tends to be rated in terms of straight watts—for example, a 40-MW transformer or a 60-MW feeder. Storage, though, is power supplied over some limited duration, so there's the added element of time.

How you express that time turns out to be important. Let's say you have a battery installation that can supply 10 MW for 4 hours. You may be tempted to describe that as having a capacity of 40 megawatt-hours, but it doesn't mean the installation can provide 40 MW for 1 hour or even 20 MW for 2 hours. Right now, the utilities and the battery manufacturers tend to use different terminology when describing the same thing. "That's been a major obstacle in the energy-storage industry," says Kamath. "We [at EPRI] try to translate so there's no confusion."

That said, the activity in battery storage is "probably a couple orders of magnitude greater than just 10 years ago," Kamath says. "Rather than isolated efforts, we're seeing major players spending serious money." Utilities, too, are much more enthusiastic about battery storage, he says, whereas in the past there was only "polite interest."

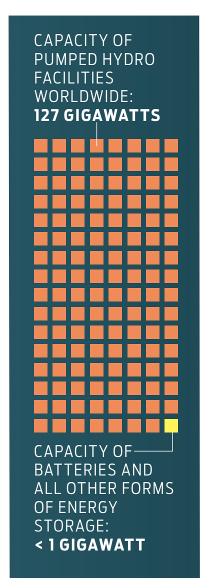
That shift in attitude was apparent last year, when the Long Island Power Authority (LIPA), in New York, put out a bid for proposals to add 2500 MW of capacity to its network. Though 15 of the 16 companies that responded proposed the usual range of generating options, AES Energy Storage, based in Arlington, Va., proposed to fulfill a portion of LIPA's needs with a 400-MW battery site.

In a densely populated area, the proposed installation would have several advantages over a traditional power plant, including 'no emissions, no water usage, no fuel lines, and no noise," says Chris Shelton, president of AES. LIPA is expected to announce the winning bids later this quarter or next.

In addition to the Long Island project, AES is pitching a similar 100-MW facility for El Paso, Texas, and several others that it has not yet disclosed to the public. By the end of last year, it had installed 76 MW of battery storage, including a recently opened 32-MW lithium-ion battery site adjacent to a wind farm near Elkins, W.Va., and two smaller deployments in Chile. The lithium-ion batteries that AES is using in Elkins can discharge their rated power for about 15 minutes, not nearly enough to make the wind farm a round-the-clock electricity source, but enough to smooth out some of the wind's variability.

The company got into grid-scale energy storage in 2007. "Back then, a 1-MW system seemed like a really big battery," says John Zahurancik, vice president of deployment and operations. "Then we moved up to 10 MW and now 32 MW. Looking out a few years, it's not hard to see 400 MW. The question is not whether we will see these things but how quickly."

Kamath is also optimistic for the long-term future of battery storage. "Once we have substantial amounts of storage on the grid, we'll see fundamental changes in the way the grid works," he says. Some proposals call for storage at the neighborhood or residential level. When you're not using your electric car, for instance, it could be parked in your garage and supplement your household electricity needs during peak hours. "You could even have storage in each appliance," Kamath says.



A refrigerator with a battery? "That day may come," he says. "Because when it's cycling on and off, it's putting wear and tear on your electricity connection, and it makes the load on the grid more difficult to control. So maybe a battery there makes sense." ❑

PAUL TEBBOTT

TOP TECH 2012

SILICON SAVIOR?
ASML's second-generation tool for extreme ultraviolet lithography is under evaluation.
PHOTO-ILLUSTRATION: ASML

AN EXTREMELY FINE LINE

2012 will be the make-or-break year for extreme ultraviolet lithography

BY KATIE M. PALMER

Moore's Law needs a hero. This year, we'll see if the chip business's designated savior—extreme ultraviolet (EUV) lithography—is really up to the task.

After decades of bringing us the incredible shrinking transistor, chipmakers are now hard up against the limits of their printing technique: Trying to use today's ultraviolet lasers to print the next generation of circuits would be like trying to trace a fine line with a preschooler's crayon.

To get a sharp enough pencil, the semiconductor industry has turned to EUV lithography. The radiation chosen for the job has a wavelength of 13.5 nanometers, around the size of the features on the next generation of chips; today's setup, which uses light with a wavelength of 193 nm, requires a series of optical tricks to write features even twice that size. To many in the semiconductor industry, EUV lithography is the only realistic option.

But you've probably heard that line before.

Fifteen years ago, researchers predicted that by about 2006, EUV chips would roll out commercially at the 65-nm node. And yet, six years later, engineers are still struggling with the dim, finicky light source at the heart of the process—despite having spent at least US $1 billion on development.

Although EUV lithography isn't ready for prime time, the technology is "not just an R&D project anymore," insists Michael Lercel, senior director of EUV product marketing at light-source manufacturer Cymer. Starting in the second half of this year, the NXE:3300, the first EUV lithography system intended for commercial chipmaking, will begin shipping to clients. The Dutch company ASML Holding, the NXE:3300's maker and the only chip-manufacturing-tool firm making EUV tools, predicts that leading-edge manufacturers will be incorporating its system into production in 2013 or 2014.

"The industrial momentum is definitely on EUV's side," says Burn Lin, vice president of research and development at Taiwan Semiconductor Manufacturing Co. (TSMC), the world's biggest independent semiconductor foundry. Companies like TSMC and Intel must settle on a lithography system as many as three years before chips go into production. The unrelenting exigencies of Moore's Law demand that manufacturers crank out chips at the 14-nm node by the end of 2013 or in 2015 at the latest. To do so with EUV lithography, they need to start retooling their fabs now.

BABY STEPS
ASML's NXE:3100 is the precursor to this year's production-ready tool, the NXE:3300.
PHOTO: ASML

Even if ASML delivers the NXE:3300s on schedule, there's a problem. By ASML's own admission, these machines still produce chips too slowly. If engineers can't get them to pick up the pace, the resulting chips will be so expensive that chipmakers will have little choice but to abandon EUV lithography. Because the industry has already invested so much, that would be bad—bad for ASML, bad for the semiconductor industry, bad even, perhaps, for the high-tech sector that has come to take for granted Moore's Law and its biannual bounty of doubled transistor densities.

But let's not get hysterical just yet. When the NXE:3300s are delivered, EUV lithography will be put to the only test that counts, that of the market. The progress chipmakers are able to make with EUV lithography this year will determine if that billion dollars was worth it—or wasted.

For approximately 50 years, optical lithography has been used, in one form or another, to pattern semiconductor wafers. Today, deep ultraviolet light from an argon fluoride laser is projected through stencil-like objects called masks onto a light-sensitive compound called a photoresist, which coats the silicon wafer. The photoresist hardens into a 3-D image of the mask on the wafer, protecting those spots from the rain of ions, baths of acid, and other processes needed to make minuscule transistors. The brighter the light, the faster it leaves its imprint on the photoresist and the more wafers chipmakers can churn out per hour. To tighten the focus of light on the photoresist, these days chipmakers circulate water between the focusing lens and the wafer.

Switching to EUV from deep ultraviolet is fraught with challenges. But "the main shortfall is the light source," says Bill Arnold, chief scientist at ASML. Simply put, it's really hard to create photons with a wavelength of 13.5 nm. And after you do create them, it's difficult to simply steer them where you want them to go.

"Nature just doesn't like EUV," quips Chris Mack, former vice president of lithography for KLA-Tencor and editor of the *Journal of Micro/Nanolithography, MEMS, and MOEMS*. Neutral atoms (like those in argon fluoride lasers) don't emit radiation at EUV wavelengths—only highly charged ions do. So engineers must create those ions by energizing tin droplets or gas into a superhot plasma. Unfortunately, the plasma emits the EUV photons in all directions, making it difficult to collect and focus them into a high-intensity beam. As a result, the second-generation prototype tools being tested now are producing just five to six wafers per hour, says Arnold. That's an order of magnitude smaller than ASML's current goal.

Even if ASML can get to 50 or 60 wafers per hour—which was its target for the end of 2011—that figure is still only a quarter of the throughput typical of one of today's state-of-the-art immersion tools. The upshot is that EUV lithography's future will largely depend on light source manufacturers' ability to eke out more photons. A lot more photons.

The first of ASML's EUV tools used a light source technology called discharge-produced plasma. Here, a lightning bolt's worth of current arcs between two electrodes through a cloud of tin vapor, creating a plasma that reaches up to 200 000 °C. Now packed with tin ions, the plasma radiates EUV light.

That strategy is now being pursued by the German company Xtreme Technologies, which has tweaked the technology by using a laser to create the initial tin gas cloud. Known as laser-assisted discharge plasma (LDP), the source can produce 30 watts of EUV light. Although that's less than a third of what ASML's goal was for the end of 2011, LDP sources have intensities comparable to those of competing sources, and they are inherently more power efficient when creating photons. But Xtreme ran into serious problems when it tried to scale up the light source. As more current is added to produce more EUV photons, generating that power and managing the heat it creates between the electrodes becomes more difficult.

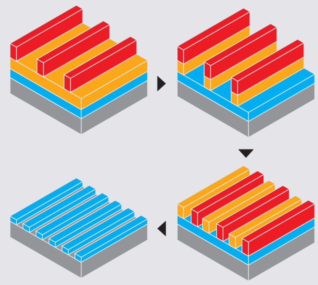
The other light source option, laser-produced plasma (LPP), seeks to avoid that problem by not using electrodes. In this technique, a carbon dioxide laser blasts moving tin droplets to produce the EUV-emitting plasma. In a recent improvement, an extra laser pulse makes a mist of the tin droplets before they get smacked with the CO_2 laser. That increases the number of tin atoms that become ionized, and therefore the number of photons that are emitted.

LPP's advantage is that the intensity of the laser can be scaled up enormously, at least in theory. "We can continue to increase the temperature and intensity of that plasma without worrying about wear on components," insists Cymer's Lercel.

These days, LPP seems to have the edge over LDP. But problems remain: Both Cymer and Japan-based Gigaphoton, which is also developing an LPP source for the NXE:3300, must filter out infrared light produced by the laser without losing EUV photons in the process. And both have had to mitigate damage from tin particles by diverting the debris, either by blowing it away with hydrogen (Cymer) or by pulling it away with a magnetic field (Gigaphoton).

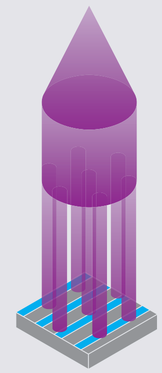
Still, the EUV sources are too dim—way too dim. "We're still not at the power levels we said we'd be at this point," concedes Lercel. By the end of 2011, ASML's road maps showed a goal of a 100-W light source, which would allow a respectable but not great throughput of 60 wafers per hour. As of last October, Cymer's source was stuck at 30 W, theoretically enough to produce a measly 20 wafers per hour.

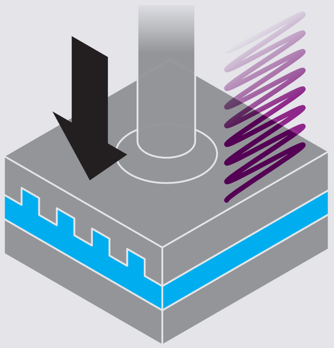
Alternatives to EUV Lithography



DOUBLE (OR TRIPLE OR QUADRUPLE) PATTERNING: Using the same 193-nanometer immersion lithography tools now used in fabrication plants, double patterning will be able to extend optical lithography to the 14-nm node if necessary. But the method requires multiple exposures to accomplish what's done in one step in older processes, multiplying costs.

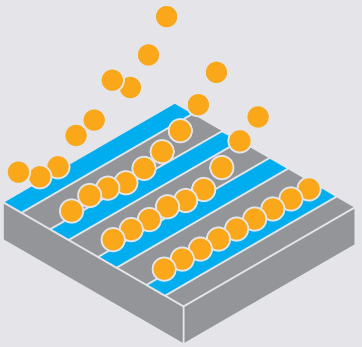
MULTIPLE ELECTRON BEAM (E-BEAM): Currently used to create photomasks, e-beam lithography can be extended to write patterns on wafers by using multiple beams at the same time. With wavelengths a fraction of an angstrom, electrons are a natural medium to write features as small as just a few nanometers. But each chip takes longer to write than with today's photolithography, and electron scattering limits the resolution of the beams.





NANOIMPRINT: Nanoimprint lithography is a deceptively straightforward idea. By simply stamping circuits, fabs could decrease costs and increase throughput. But imprints need templates, and those templates will themselves need to be written with a high-resolution lithography technique and maintain their patterns while stamping wafers thousands of times.

DIRECTED SELF-ASSEMBLY: The only "bottom-up" manufacturing technique under consideration, self-assembly is also the furthest away from implementation. The concept uses optical lithography to form a simple pattern, followed by the addition of chemicals called block copolymers that assemble themselves into regular arrays along that pattern.



JAMES PROVOST (4)

Moore's March

Intel has the most aggressive road map for scaling down transistors. It may not use EUV until 2015, if at all.

2007	2008	2009	2010	2011	2012	2013	2014	2015
45-NANOMETER NODE: DRY 193-NM LITHOGRAPHY		32-NM NODE: 193-NM IMMERSION		20/22-NM NODE: 193-NM IMMERSION, SOME DOUBLE PATTERNING		14/16-NM NODE: 193-NM IMMERSION, SOME MULTIPLE PATTERNING		10/11-NM NODE: **EUV?**

Manufacturers are focusing on source power for obvious reasons: Without reaching a higher wattage, EUV lithography won't be any more economical than today's plan B, which is to use a version of today's 193-nm immersion lithography in which the wafers are exposed two, three, or even four times in order to make features that are fine enough. This technique, called multiple patterning, is also expensive, because it takes two to four times as long to write a single pattern on a wafer. Even so, to compete with multiple patterning, lithography guru Chris Mack estimates, EUV lithography must be able to support the production of 150 wafers per hour, which will require a light source with 200 to 350 W. ASML thinks that EUV lithography will be competitive at 70 wafers per hour and plans to hit 125 wafers per hour by mid-2013, which would take 250 W.

The throughput problem affects more than production efficiency—it has a drastic impact on the rate at which engineers can perform essential process development and troubleshooting. For example, with throughput at today's levels, mask makers can't determine how fast their masks will degrade from constant bombardment by high-energy photons. Resist makers similarly need access to EUV exposures and to know the final source power so they can design a chemical that will actually work at those intensities, says Mack. "All the resist suppliers say they need more tool time so they can run more samples," says ASML's Arnold.

Until those parts can be adequately tested, it's unclear whether an unforeseen engineering challenge—an unknown unknown—will stop EUV lithography in its tracks. It's happened before, says Mike Mayberry, vice president of Intel's technology and manufacturing group and director of components research. A tool might have a bright light source and great optics, he says, but it may just as easily have an unexpected source of contamination or vibration: "You never know what will be the weakest link."

"It's like peeling an onion," adds Mack. EUV lithography's greatest problem is that manufacturers are just now drawing away its outer layers, and there are likely to be a lot of them.

With EUV, almost every element of the lithographic method needed to be redesigned: The entire process is conducted in a vacuum, it uses mirrors rather than lenses, and mask and resist technologies must be substantially altered to deal with the new wavelength. "This is the most challenging lithographic technology we've tried to implement in manufacturing," says Harry Levinson, manager of strategic lithography technology at GlobalFoundries. "As an industry, we're very good at making advances when one or two or three things have to change. But when we have to change 5 or 10, that's when things get difficult."

Moore's Law won't grind to a screeching halt if EUV lithography isn't ready, of course. Multiple patterning with 193-nm immersion will still act as the industry's expensive safety net, and there are a number of more experimental technologies in development, including writing patterns using multiple electron beams, stamping circuits with nanoimprint devices, and the chemical trickery known as directed self-assembly. But EUV lithography is years ahead of any of these options in spending, and it continues to siphon off most of the R&D money.

The experimental alternative that's closest to implementation might be electron-beam lithography. Those machines are still in earlier developmental stages than EUV lithography and have poor throughput, but this year TSMC is evaluating two e-beam tools alongside ASML's second-generation prototype tool. TSMC's Lin is blunt about which way he is leaning: "We need a robust working tool by 2013, and I personally have a preference for multiple e-beam direct writing systems," he says.

For TSMC and others, EUV lithography is reaching the end of its rope. "There's always a point when [customers] will lose faith if the delays go on too long," concedes Cymer's Lercel.

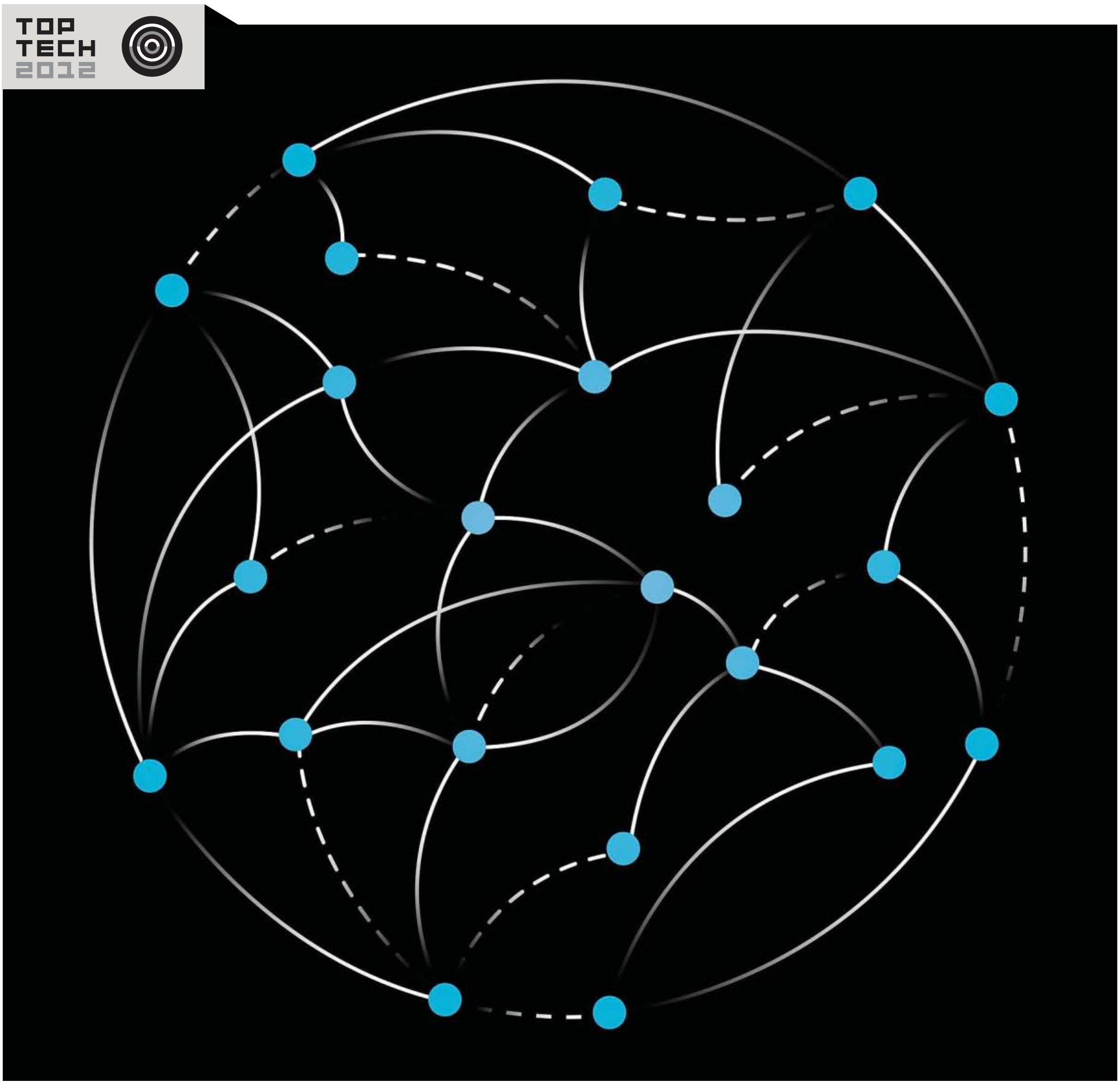
And they are rapidly approaching that point, says Mack. Many chipmakers are facing a crucial decision this year about which technology will see them through to smaller features and pitch sizes, thereby keeping Moore's Law marching along. How fast it marches will depend in no small measure on what happens with EUV lithography. ❑

Return of the Zeppelin

2012 TECH WATCH

This year a British engineering company, Hybrid Air Vehicles, will start work on a new breed of airship able to lug up to 20 metric tons of mining gear and supplies to remote arctic outposts. The company also has a bullet-resistant battlefield surveillance blimp in the works.

PAUL TEBBOTT (2)



FANTASTIC 4G

Hundreds of telecoms will invest in 4G LTE networks in 2012 **by Marisa Plumb**

It's 5:00 in the afternoon. Do you know how much data your smartphone apps are sucking out of the ether?

It's probably at least 10 megabytes per hour, and it may be as much as 115 MB/h, according to a recent study by the British firm Virgin Media Business. In other words, depending on what you're using it for, your phone or tablet might be consuming—or more likely struggling but failing to consume—the data equivalent of about 100 medium-size books every hour.

If you're on a 3G network, you have our sympathies. But cheer up: 4G is coming to a cellphone tower near you, if it hasn't already. With a conformity rare in technology, let alone in perennially fractious telephony, the world's wireless operators are falling in line behind a 4G standard called LTE, which stands for Long Term Evolution. According

ieee spectrum Previous Page | Contents | Zoom in | Zoom out | Front Cover | Search Issue | Next Page Qmags THE WORLD'S NEWSSTAND®

400%

Growth in 4G LTE subscribers in 2012

to the market research firm iSuppli Corp., the number of 4G LTE subscribers will grow by 400 percent this year, and about 10 percent of global wireless subscribers will have LTE connections by 2015.

Today's LTE networks deliver data download rates about 10 times those of 3G while making more efficient use of the radio spectrum. Basically, 4G LTE can keep up, if just barely, with the soaring data demands of the fast-growing ranks of ever more sophisticated smartphones.

Most smartphones can already accommodate data at rates that exceed the networks' capabilities, says Paul Kapustka of Sidecut Reports, a service that analyzes carrier technologies. Given the chance, broadband phones will choke their wireless networks to death. Telecom equipment makers such as Alcatel-Lucent and Ericsson have convinced network operators around the world that LTE is the technology that will keep their networks moving fast.

10x
Increase in the data download rate for LTE 4G compared to 3G

The Global Mobile Suppliers Association reports that 4G LTE networks are being built by 280 operators in 90 countries, and dozens of these networks will light up the airwaves in 2012. It's easy to see why. Increasingly, people are using their phones and tablets to stream music, movies, and television shows; check in with their social networks; place two-way video calls; and even have virtual visits with their doctors. All those bandwidth hogs are more reliable and fun to use with LTE. Indeed, within a year of the Swedish telecom TeliaSonora taking its 4G LTE network live, the average users' monthly download total rose to about 15 gigabytes from about 3 GB. LTE is fast enough to support such features as high-definition video. So Phil Solis, research director of mobile networks at ABI Research, predicts a sharp rise this year in users of video call services like Skype, FaceTime, and Fring.

LTE networks are not all created equal, but early rollouts are more than validating backers' claims of a tenfold speed increase over 3G. In Australia, a 3G connection averages just under 2 megabits per second, says Mike Wright, executive director of Telstra Corp. networks and access technologies. When Telstra, the country's largest telecom, launched a 4G network in 2011, average download speeds rose to 20 Mb/s. In Dallas, between April and October of 2011, Verizon launched a new LTE network and saw a jump from around 0.75 Mb/s to between 11 and 14 Mb/s, according to data analysts at RootMetrics. That's about double the speed most Americans get through their cable and DSL broadband services.

It's good news for the millions of people who primarily use their cellular connections to access the Web. And the good news doesn't stop there. Mobile connections at 4G speeds are supercharging older platforms as well: Forty percent of today's 4G consumer devices are routers that bring the Internet to one or more computers, and 25 percent are dongles for laptop computers.

LTE and 4G have not always been one and the same. LTE was once one of two standards marketed as 4G. However, decisions in the past year have effectively edged out LTE's competitor, WiMax. The U.S. operator Sprint, which initially deployed WiMax, will build out a separate LTE network this year. Even though the company's WiMax service will be around for some time, nobody expects it to be a long-term solution. LTE's triumph is all the more remarkable considering that WiMax had a head start.

LTE and WiMax both qualify as 4G networks because they each use an all–Internet Protocol scheme to streamline their architectures and boost data rates. In the future, they'll be capable of delivering data, including digitized voice, in packets, just like on the Internet. For now, LTE is capable of handling only data. Voice calls are handled on an operator's 3G or 2G network or by applications that use a different layer of the network to deliver voice over IP (VoIP), like Skype. But upgrades that will start this year and continue through 2014 will pave the way for always handling voice exactly like data.

In a typical IP network, packets are assigned labels that indicate how they fit together, so that they can be sent over any available channel and reassembled when they reach their destination. To access a website, a smartphone on an LTE network connects to a base station, or an "evolved node" in LTE parlance. This station is typically a 3G base station upgraded with more processing power to handle packet-switched data and radio technology for LTE's different bands of spectrum. For now, an individual LTE base station works on one spectral band, but there will be an upgrade to allow for multiband evolved nodes in the next few years.

Packetized data then streams between the node and smartphone over the widest available of several channels within a spectral band. The evolved node then connects to what's called an evolved packet core. The EPC, which processes data and sends and receives video images, Web pages, and soon, voice, can connect to all kinds of other networks.

Because 4G uses IP, like the Internet itself, the data's trip from the base station to the Internet or other networks can use any means—copper, fiber, terrestrial microwave, or satellite. But before it can do that, the data stream must first be tweaked by another layer of technology called the IP Multimedia Subsystem. IMS helps optimize bandwidth for each application, for instance, by guaranteeing a certain maximum latency for VoIP traffic.

The LTE scheme is a lot simpler than 3G, which requires a temporary but dedicated connection between a device and a base station to transmit information. That connection is divided into time slots, with each device occupying its own slot, even when there's silence during the conversation.

Although WiMax handles voice just as it does any other data, the carriers that tried it out are now switching to LTE. So why is LTE emerging as the clear favorite? One reason is capacity. The LTE specification promises peak download rates of 100 Mb/s. WiMax could match that speed in the future, but early versions fell short and don't use a carrier's available spectrum as efficiently as LTE. The latest version of WiMax is more efficient, however, so the performance gap between the two technologies is likely to narrow.

According to Solis of ABI Research and Kapustka of Sidecut Reports, one big reason LTE will remain ahead is a campaign against WiMax by the companies with the biggest stakes in LTE technologies. Qualcomm, for example, owns many patents for LTE technology, while one of its biggest rivals, Intel, has been the driving force behind WiMax. Alcatel-Lucent and Ericsson have also invested a lot in LTE equipment and were highly motivated to push LTE in influential U.S. markets, says Kapustka.

280
Network operators investing in 4G LTE networks

It is worth noting that neither technology's maximum download speed is a reality yet. Clearwire Corp., which provides Sprint with the most extensive WiMax network in the United States, delivers average speeds under 7 Mb/s. So far, commercial LTE networks have posted much higher average speeds. In some countries, like Australia and Sweden, average LTE download rates are more than 20 Mb/s in urban areas.

All-IP networks are inevitable, and operators would like to install them everywhere overnight. But the upgrade will be gradual, and 2G and 3G networks will be around for years to come. It's not that upgrading a 3G base station to LTE is always a terribly demanding or disruptive process, says Todd Rowley, vice president of 4G technologies at Sprint. It's just that during the deployment, the entire coverage network and its devices need to work seamlessly with both LTE and the existing 3G networks.

Because 4G and 3G can't occupy the same bands, there's been a scramble for spectrum. Carriers will have to either buy new spectrum from other companies or at auction, or they'll have to repurpose bands from less-populated 2G networks.

It's been easier to manage such spectrum swaps in some countries than in others. Australia, for example, seems to have handled things with minimal disruption: Telecom giant Telstra was able to repurpose its 2G band, at 1800 megahertz, for its 4G network because its base of 2G subscribers had dwindled significantly, says Telstra's Wright. Even better, the 1800-MHz band is the LTE standard for Europe and other countries, so radio gear designed for it is readily available.

Elsewhere, the transition hasn't been so smooth, because telecoms had to horse-trade to get spectrum for 4G.

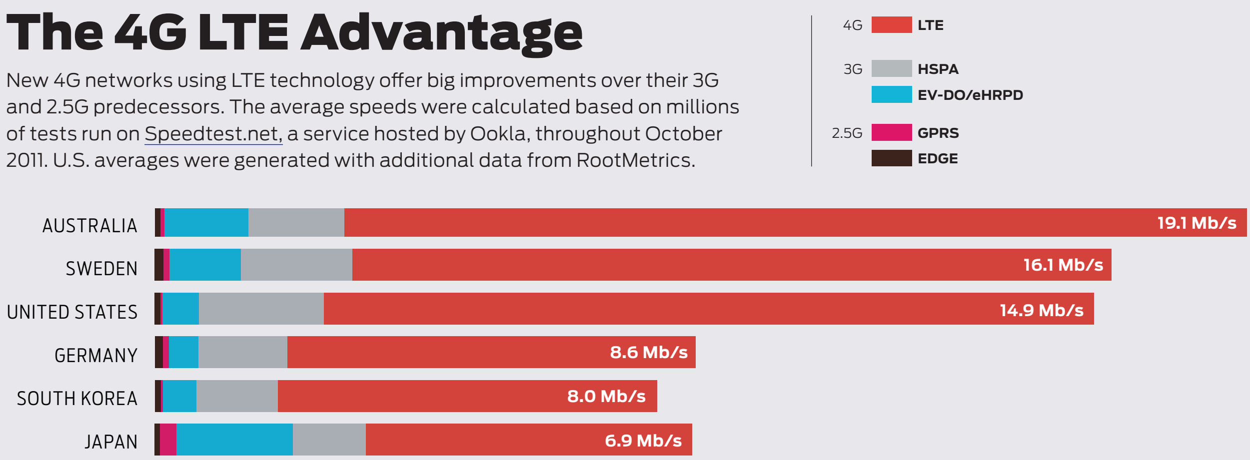
"LTE is enabling more capacity for data services, but it's also increasing the range of scenarios that a device needs to work in," says Bill Davidson, senior vice president of global marketing and investor relations at Qualcomm. "Different countries have auctioned off the 700-MHz band, then the 2.5-gigahertz band, then 800 and 900 bands of spectrum over the last few years, and that's made it more complex for us." To cover all the bases, Qualcomm's latest high-end handset chips can accommodate up to 40 bands. And Ericsson, which makes 4G base stations, sells equipment for at least 15 different bands.

These challenges aren't stopping anyone. But telecoms have to get their new systems up in a hurry—even as LTE networks are being rolled out in major urban centers, LTE's successor is already being planned: LTE-Advanced promises faster data rates, wider channel bandwidths, more advanced antennas, and support for a larger number of low-power "picocells" to increase coverage. It will offer another boost in efficiency that's just as irresistible as was LTE's.

"It's the drive for spectral efficiency that will always motivate operators to use the newest technologies," says Terry McCabe, chief technology officer at Mavenir Systems, which provides VoIP for LTE networks. And so networks, even those meant for the long term, will continue to evolve. ❑

The 4G LTE Advantage

New 4G networks using LTE technology offer big improvements over their 3G and 2.5G predecessors. The average speeds were calculated based on millions of tests run on Speedtest.net, a service hosted by Ookla, throughout October 2011. U.S. averages were generated with additional data from RootMetrics.



SOURCE: OOKLA AND ROOTMETRICS

TOP TECH 2012

UP, UP, AND AWAY

This year, commercial spaceflight will really take off

BY JAMES OBERG

The 20th of February, 2012, will be the 50th anniversary of the first U.S. orbital manned spaceflight. To mark the occasion, retired pilot Craig Russell had an over-the-top idea: Reenact astronaut John Glenn's mission, but do it with private funding and off-the-shelf technologies.

Ultimately, a lack of funding killed Russell's dream, but don't lose heart. Truth is, if you've got a more practical reason for putting a person in space, there's never been a better time to try. Over the last decade, a broad advance in the commercial availability of aerospace technologies has allowed small private entities to attempt feats that once had been the monopoly of major governments.

In 2012 privately funded human spaceflight will advance from promises and one-off stunts to serious flight-testing of spaceships. Governments will be the biggest customers, with unmanned systems possibly docking with the International Space Station (ISS) this year and perhaps eventually taking the place of the retired U.S. space shuttles. Meanwhile, spacecraft designed to give well-heeled tourists a thrill will be firing up their rockets, letting their passengers enjoy a few minutes of weightlessness, and gliding in for landings.

Indeed, this could be the year that spaceflight moves beyond the 1960s inspirational phrase "man in space" toward a more inclusive one: "*Any* man or woman in space."

In spaceflight, as in many other fields, there's an advantage to being first. Virgin Galactic has that advantage. Its *SpaceShipTwo* is the roomier follow-up to the craft that won the Ansari X-Prize in 2004 for crossing the legal boundary of space (100 kilometers). The British company has already sold nearly 500 tickets at US $200 000 apiece, and it opened a spaceport this past October in New Mexico.

In 2012, "our hope, our plan, is to do powered flight tests, and if things go well, we have a shot of getting into space," says CEO George T. Whitesides. Using the large *WhiteKnightTwo* aircraft as a carrier, the rocket plane has already begun unpowered drop tests from its development base in Mojave, Calif. And it recently concluded ground-

FUN RIDE
Virgin Galactic's *SpaceShipTwo*, attached to its carrier, *WhiteKnightTwo*, should be making test flights this year.
PHOTO: VIRGIN GALACTIC

based engine burns that were nearly long enough to put a vehicle into space. Full-duration burns will last between 60 and 70 seconds during an ascent that involves a little less than 4 *g*'s of acceleration.

Actual test flights will be made in small steps, Whitesides says. Turning the engine on and off will be a first step, followed by a 10-second burn, a 20-second burn, and so forth. When asked how many test flights there would be before the first tourists fly, he laughed, saying, "As many as you need."

The other tourist spaceship that is expected to get airborne in 2012 is the *Lynx* rocket plane from Xcor Aerospace, in Mojave. Its concept is less grandiose than *SpaceShipTwo*'s, with a single passenger sitting in a cockpit next to a single pilot and with initial flights to altitudes of just over 60 kilometers. Company spokesman Mike Massee says the rocket plane's propulsion system was designed for speedy testing and will eventually allow for two flights per day using a single ground crew.

You can also expect to hear more about Amazon.com founder Jeff Bezos's secretive spaceflight company, Blue Origin, based in Kent, Wash. Little was known about its spacecraft, *New Shepard*, which takes off and lands vertically, until an unmanned supersonic test flight this past summer ended in an emergency engine shutdown and the crash-and-burn loss of the vehicle. Another craft from the company is expected to fly this year and at some point could carry one or more test pilots. While it's unknown what altitude pilots will be aiming for, breaking the 100-km barrier is the likely goal for selling seats to passengers.

Up and down isn't the only human spaceflight game in town. The more important work, from a commercial and scientific perspective, is orbital flight. And that arena, too, could pass real milestones this year. Some suborbital tourist firms have dreams of eventual orbital flight, but others are going straight for it.

In terms of spacecraft engineering, the step from short suborbital missions to orbital flight is about two orders of magnitude of energy, vehicle stress, and general complexity. Private ticket prices reflect that: Initial suborbital *SpaceShipTwo* prices start at $200 000, while space tourist trips to the ISS in a Soyuz have ranged from $20 million to $40 million.

NASA hopes that at least one corporate team will succeed in developing an Earth-to-orbit "space taxi" in the next few years, so it can stop paying Russia $65 million per seat on Soyuz vehicles. If the price is low enough, that same operator could someday also sell tickets to other orbital destinations, should there ever be any—and some are under consideration. But at recent hearings in Washington, D.C., some U.S. congressmen expressed serious skepticism about whether a private market for such flights would ever evolve while the ticket prices remain in the multimillion-dollar range.

DRAGON, FLY
SpaceX's *Dragon* capsule will see testing this year.
ILLUSTRATION: SPACEX

That's why SpaceX's *Dragon* flights this year are so important. The firm, based in Hawthorne, Calif., plans two unmanned resupply runs to the ISS. If successful, these cargo flights will help establish a track record that could eventually lead NASA to approve a SpaceX craft for manned flights. Before that happens, though, SpaceX needs to finish developing and testing its launch escape system.

Two other orbital projects in the works include a shuttle-shaped craft built by Sierra Nevada Corp. that repurposes a surplus Soviet-era design, and a modernized version of the Apollo capsule from Boeing. Sierra Nevada's *Dream Chaser* will be tested in the second half of the year. It will be carried to altitude and dropped by Virgin Galactic's *WhiteKnightTwo*, and it will then glide under autopilot and land itself. Future flights could be flown by test pilots, but Sierra Nevada has not been forthcoming. These tests, say experts, should help dispel persistent concerns among some spaceflight professionals about the design's controllability. Boeing's craft, the CST-100 (for Crew Space Transportation), is further from flight-testing.

Little is known about the spacecraft from Excalibur Almaz, except that it's based on a Soviet manned vehicle, with modernized innards, and is launched by a commercial booster. Company official Arthur Dula states that it "could provide a crew vehicle two years earlier than the current NASA plans." The company, headquartered on the Isle of Man, recently inked a development agreement with NASA and will spend 2012 on design and safety reviews, not flight-testing.

Harsh reality will eventually sort out the winners from the losers, but for now the field of contestants is satisfyingly broad, as they exploit combinations of classic, proven ideas with bold new innovations. Successes and failures are likely to be spectacular, as the competing projects attempt to push open a wider way for human access to space. Expect a sky full of excitement this year. ❏

The Year in Space, Almost

Company	Spaceship	2012 Goals
Virgin Galactic	*SpaceShipTwo*	Powered test flight
Xcor Aerospace	*Lynx*	First test flights
Blue Origin	*New Shepard*	Unknown
SpaceX	*Dragon*	Two resupply trips to the International Space Station
Sierra Nevada Corp.	*Dream Chaser*	Drop tests
Excalibur Almaz	A variant of a Soviet spacecraft	Design and safety reviews

TOP TECH 2012

State of Charge

2012 will test the feasibility of EV charging stations

by Lawrence Ulrich

In a cloud of car exhaust during a Friday rush hour, I'm humming over San Francisco's Golden Gate Bridge in an all-electric, tailpipe-free Nissan Leaf. I've plotted a course for Vacaville, 88 kilometers (55 miles) north, known for its sprawling outlet mall. However, I seek not a shopping retreat but an eco-electric enclave, for this city is in the vanguard of a government-subsidized drive to build the first network of public electric-vehicle charging stations in the United States. ■ Throughout this year and into 2013, the top organizations in EV charging technology will be wrapping up projects backed by more than US $130 million in federal stimulus money and Department of Energy grants. And with thousands of public chargers coming on line, Vacaville's beta-scale program joins the latest, politically charged controversy over the electric car: Is public charging a necessary spark to ignite mass-scale EV adoption?

Surprisingly, many key players in the automakers' EV programs are unenthusiastic about the rollout. Many of them insist that most buyers will charge at home first, workplace second, and rarely, if ever, need a public fill-up. "We see public charging as a nice-to-have, not a need-to-have," says Aaron Singer, product manager for electric vehicles at BMW.

Yet proponents say that public charging is as critical as the cars themselves. Nissan is a prime example. "As a company, strategically, we look at public charging as an accelerator to EV adoption," says Mark Perry, Nissan's chief product planner for North America.

Without public charging, "EVs will be tethered to homes, a niche application," says Don Karner, an electrical and nuclear engineer who is cofounder and president of ECOtality, a San Francisco–based charging company. "We can do better than that."

Vacaville's pioneering effort also spotlights the challenge of birthing a nationwide EV infrastructure that might dent Big Oil and its vast network of more than 100 000 U.S. gas stations. It's a system that has trained drivers to expect, without a second thought, to fill up in 3 minutes flat and drive hundreds of kilometers before having to do it again.

I've come to Vacaville to plug in to one of the United States' first DC—sometimes called Level 3—fast chargers. This 480-volt, 50-kilowatt beast can fill my burgundy Leaf to 80 percent capacity in 30 minutes. My plan is to drive all weekend without using a drop of gasoline or spewing a whiff of tailpipe pollution. That includes my run to Vacaville's high-powered charger, strategically perched between San Francisco and Sacramento, allowing EV owners to bridge the gap between two major cities. EVs can still use a standard 120-V household plug, but charging takes up to 24 hours on that Level 1 power.

Home base for the weekend is the Parc 55 Wyndham Hotel in San Francisco's Union Square, among a handful of area hotels offering free fill-ups on Level 2 stations. These 240-V AC units are simply heavy-duty versions of the home stations used by the Leaf and other models. Delivering 3.3 kW per hour, they can fill a Leaf's 24-kilowatt-hour

AHHH! DIRECT CURRENT...
The author's all-electric Nissan Leaf satiates itself with a superfast charge.
PHOTO: MARK RICHARDS

RANGE ANXIETY
When the Leaf's battery warning light goes on, there'd better be a high-powered socket in sight.
PHOTO: MARK RICHARDS

battery in 7 hours or the 16-kWh battery of a Volt plug-in hybrid in 3.5 hours.

At the hotel, I pull up to the free JuiceBar brand charging station, created by BMW Group's DesignworksUSA, and connect its cable to the Leaf. Two hours later, after catching up on e-mail, I've topped off the battery, leaving me range to spare for my run to Vacaville.

Level 2 is the go-to technology for 95 percent of home and commercial stations coming on line. And the latest Level 2 chargers run at 6.6 kW, charging in half the time as the 3.3-kW units. The charger for the $39 995 Ford Focus Electric, hitting the market right now, is the first 6.6-kW unit for home use. Manufactured by Leviton and sold and installed for $1499 through Best Buy, the charger can restore the Focus's 160-km driving range in 3.5 hours.

"Four hours or less is the sweet spot," says Richard Lowenthal, chief technical officer of the California-based charging company Coulomb Technologies. "Everyone works or sleeps more than that."

The biggest installer of Level 2 chargers is ECOtality, which is spending $230 million, including $115 million in Department of Energy grants, to install nearly 15 000 Blink brand charge stations in six states and the District of Columbia, most of them Level 2s.

ECOtality manages the DOE-sponsored EV Project, which is giving 8600 EV buyers free chargers and letting companies collect real-time feedback on driving patterns and energy usage. The project is also adding about 5000 public chargers, including 225 fast chargers in 18 major metro areas, including Houston; Los Angeles; Phoenix; Portland, Ore.; San Francisco; the Tennessee Triangle (Nashville, Knoxville, and Chattanooga); and Washington, D.C.

So far, a recharge is typically free at any of the program's public charging stations. But nobody expects that to last forever. So charging companies are looking to put their chargers at places such as big box stores, where they can charge for a charge, thereby flourishing without government subsidies. It won't be easy: Although Level 2 chargers cost only $1500 to $3000, a DC fast charger, capable of 80 percent charging in 30 minutes, can cost up to $50 000, including installation. Utilities may charge exorbitant rates to access quick-charge power, dampening prospects for station owners and users. But to spur adoption, Nissan recently released a groundbreaking compact 480-V quick charger that will sell for $9900, plus installation.

"Our competition isn't gasoline, but affordable home electricity," says ECOtality's Karner. In some states, home chargers will enjoy discounted off-peak nighttime rates as low as 5 cents per kilowatt-hour. Even at the national average of 11 cents, a Leaf can cover 160 km for about $2.75. Compare that to the $16 you'd spend in a typical car that runs at 9.4 liters per 100 km (25 miles per gallon) at $4 per gallon. Somewhere in between is the profit point for station hosts, with drivers paying partly for service, partly for a convenient parking space.

Batteries last longest and perform best when they avoid rapid cycling and extremes of hot and cold. Yet the faster they charge, the more heat is produced. Engineers face a balancing act: how to stuff batteries quickly while assuring that they'll hold up for eight years and 100 000 miles (161 000 km), as most warranties stipulate.

The trick is managed with smart electronics. Chargers communicate with cars' onboard chargers via digital signals to monitor state of charge and battery temperature, adjusting the power level as needed. Battery systems also cool themselves: For instance, the Volt battery circulates liquid coolant around each of its 288 cells.

For household and Level 2 chargers, rectifiers onboard the car convert grid current into DC. DC chargers stuff juice directly into the battery, but at an industrial strength—roughly 480 V, 100 amperes, and 60 kW.

The Higgs Boson

2012 TECH WATCH

Tantalizing hints of the elusive particle, which arises from ripples in the field that gives particles their mass, appeared in December. As physicists working at CERN collect more data, the particle could be officially recognized or else recede from view.

To preserve their batteries, EVs are programmed to cut off fast charging at 80 percent capacity. Lithium-ion car batteries have yet to establish a record, but Nissan suggests that constant quick charging will reduce capacity by 1 percent per year beyond normal levels. The company is developing a charger based on work at Kansai University, in Japan, that replaces a carbon electrode with one made from tungsten and vanadium oxides, allowing 10-minute charges without harming batteries.

But for now, 30 minutes is the target—one that some experts say poses no big challenge to gasoline cars.

"People misunderstand what 'fast' charging is going to deliver," says Britta Gross, director of global energy systems and infrastructure commercialization for General Motors. "A fast-charging network doesn't turn an EV into a long-range vehicle."

What fast chargers can do, though, is ease the oft-cited problem of "range anxiety"—the dread of running out of juice and being stranded miles from a plug.

"To make electric transportation useful, we have to extend range," Karner says, "and adding infrastructure is more cost-effective than adding heavy, expensive batteries to the vehicle."

Sounds good, in theory. But stations could gather dust, awaiting customers who never arrive. "The restricted parking spot with a charger that sits day after day unused will give the industry a black eye," Gross predicts.

I don't have 7 hours to blow at Vacaville's outlet mall, but the quick-draw DC charger fortunately awaits, in a park-and-ride lot behind a Sonic Drive-In. I'm met by Vivek Narayanan, electric and natural gas vehicle product manager for Pacific Gas and Electric Co. in San Francisco. He pulls up in a Chevy Volt and plugs in to one of six Level 2 units alongside the big Eaton DC charging unit. We're the only customers.

Narayanan unlocks the DC charger, and I connect its unwieldy plug—roughly the size and weight of a power drill—to the Leaf's fast-charge port, a $700 option on the $36 050 car.

The unit rattles and hums, and then... nothing. The charger can't establish communications with the Leaf, and the screen flashes an error message. It wouldn't be the first time that I've encountered an inoperable public station.

After a phone call to a PG&E tech, we get it working. The Leaf sucks up a charge in 32 minutes, barely enough time to grab a burger at the nearby drive-in.

Japan currently leads the way in EV fast charging, with nearly 1000 public units (compared with fewer than 100 in Europe). Tokyo Electric Power Co. and some Japanese automakers set the standard—followed by the makers of almost all other fast chargers, mine included—called CHAdeMO, which loosely means "charge to move." But the U.S.-based SAE International is readying a new standard that modifies today's J1772 connector to incorporate household, Level 2, and high-powered DC charging within a single "combo" connector. The SAE's proposal is backed by American and European automakers, which prefer the new plug and perhaps don't mind sticking it to Nissan, which was first to the U.S. market with a quick-charge EV.

8 YEARS AND 100 000 MILES
Auto battery warranty goal

ECOtality, for now, will roll out DC chargers with dual cords to support cars on either standard.

"We're the tail of the dog here," ECOtality's Karner says. "But car companies are playing a dangerous game, trying to smoke out the Japanese, at the risk of leaving the public with VHS and Beta again."

Jack Pokrzywa, manager of SAE's ground vehicle standards, calls the combo plug a more elegant solution: Cars need only a single receptacle, rather than the space-hogging dual sockets of the Leaf, to accept any rate of charge. The combo plug can handle up to 600 V and 90 kW, opening the door to charges in as little as 10 minutes—nearly as quick as you can pump a tankful of unleaded.

As it turns out, my Nissan's 80-percent-full battery gives me some range anxiety on my 88-km return trip to San Francisco. Driving a steady 88 km per hour to preserve power, I roll into my hotel in Union Square with a gauge showing 13 km of remaining range. Whew. But the point has been proved: Vacaville's electric oasis could have enabled me to go from San Francisco to Sacramento and back in one day.

Cities, of course, remain the EV's natural habitat. I plug the Leaf into the hotel's charger and head to my room. Three hours later, I've got ample power for cruising to dinner, plus sightseeing the next day. As automakers, charging outfits, and governments feel their way into the electric age, they're using cities as labs and early adopters as guinea pigs. Mistakes will be made, Nissan's Perry says.

But though electric mobility has stumbled before, it may be unwise to see its latest baby steps and assume it will never walk or run.

"There will be places with more cars than chargers, and places with more chargers than cars," Perry says. "Two years from now, we'll all be a lot smarter." ❑

PAUL TEBBOTT

TOP TECH 2012

CHINA'S HOMEGROWN SUPERCOMPUTERS

This year, China's chips will power the Dawning 6000

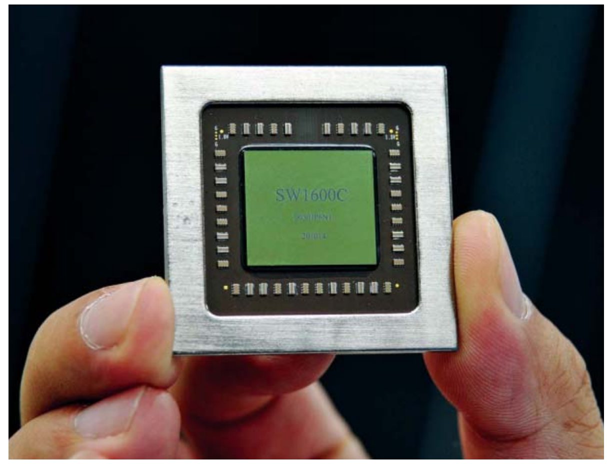
BY JOSEPH CALAMIA

In late October 2011, the Sunway BlueLight MPP made headlines as China's first high-performance computer to harness the power of a homegrown chip, the ShenWei SW1600. And the Dawning 6000, scheduled to come on line in December 2011, will use another indigenous processor, the Godson-3B. These are supercomputers that China can truly call its own.

At press time, engineers were busy optimizing the Dawning 6000's ability to run Linpack—the benchmark software library used to rank computers in the Top500 list. The Sunway BlueLight, a petaflops-level supercomputer, has already been put through its Linpack paces and claimed 14th place in the November Top500 ranking. But don't be fooled: Neither machine is a speed demon. Consider them rather as steps toward technological independence.

"The Dawning 6000 is really trying to master the tricks of this domain so that the Chinese have the ability to develop their own chips, their own IT from the ground up," says IEEE Fellow Tarek El-Ghazawi, a professor of electrical and computer engineering at George Washington University and a codirector of the NSF Center for High-Performance Reconfigurable Computing. Given that today's exotic supercomputer components are tomorrow's quotidian hardware for personal computers, El-Ghazawi predicts that these research projects will prove a boon for Chinese commercial chips, which he expects to become widespread

GREAT WALL The Sunway BlueLight supercomputer is the first deployed using processors designed in China.



HOMESPUN LOGIC The ShenWei SW1600, which was designed in China, powers the Sunway BlueLight supercomputer.

XU SUHUI/XINHUA/LANDOV (2)

in China's marketplace in around 10 years. "Then, in the next 20 years," he says, "they may be selling chips to the world, including the U.S."

That would be a swapping of roles. The Dawning 5000 line, released in 2008, relied on U.S.-made AMD Opteron CPUs. And even China's Tianhe-1A, for a few months the world's top-ranked supercomputer, owed a good part of its 2.57-petaflops performance to Western chips—a total of 7168 Nvidia Tesla GPUs complemented by 14 396 Intel Xeon CPUs.

"The Tianhe was opportunistic," El-Ghazawi says. "They looked at the top-performing chips out there and applied them. With Dawning, from the ground up, they are building a machine with careful consideration to each level of the architecture—chip, node, and system—with the requirements of the software in the back of their minds."

The Tianhe-1A did not sacrifice all innovation in the race for the top. The machine was also celebrated for its indigenous interconnect system, the channels for shuttling information between computer nodes. The interconnect system, called Arch, was developed by China's National University of Defense Technology. Capable of 160 gigabytes per second, Arch had greater bandwidth than commercially available alternatives, such as InfiniBand.

"If you're developing your own supercomputer, you would have to build both your own processors and interconnect to connect them together," says Jack Dongarra, a professor of electrical engineering and computer science at the University of Tennessee who helps to compile the Top500 ranking. "I would guess that the Chinese would want to move toward a system that they have developed themselves.…They want to be in a position where they can develop an industry that can generate computers for China and the rest of the world rather than relying on Western components."

Different supercomputers represent different strategies, argues David K. Kahaner, founding director of the Asian Technology Information Program, headquartered in Albuquerque. For example, the Tianhe-1A, still the fastest machine in China, and the Sunway BlueLight have roots in defense research, while the Dawning 6000 might be thought of as an academic research supercomputer. "China is a big country with a tremendous number of capable people, and they are striking out in a number of directions," Kahaner says. "Competition is good for everybody." Right now, he sees the BlueLight as the most indigenous, noting its use of both homegrown chips and a unique water-cooling system.

None of the machines has completely broken away from Western influences. For example, the Dawning 6000's Godson-3B processors, from the Chinese Academy of Sciences, appear to use a Western instruction set—the CPU's overarching architecture as it relates to programming. The MIPS instruction set, which Godson uses, is more commonly found in the microprocessors inhabiting television set-top boxes. Mark Pittman, MIPS Technologies' vice president for Asia and Pacific sales, says the Chinese Academy of Sciences was one of the first groups to target the MIPS instruction set for high-performance computing. Early in the project, the Godson researchers used the instruction set without a license, but Pittman notes that this issue has been resolved, adding that since 2009

TOP TECH 2012

his company has directly licensed MIPS to the academy's Institute of Computing Technology.

"Leading researchers in China feel it is better to innovate a microprocessor with an existing instruction set rather than take a long time to develop an instruction set and then innovate a processor based on that," Pittman says. Developing a new instruction set would require porting existing operating systems, programs, and drivers. "All the things that run on MIPS would have to be re-created for a new instruction set, and even in China that's an expensive proposition."

The BlueLight's ShenWei SW1600, made by the National Research Center of Parallel Computer Engineering and Technology, is rumored to have taken one step further toward independence. Though earlier ShenWei chips used a modified Alpha instruction set, designers claim this processor uses an architecture of their own design, Kahaner says.

Both machines may also still use Western interconnect systems. Kahaner confirms that the BlueLight uses a modified InfiniBand interconnect system. El-Ghazawi says a prototype node of the Dawning 6000 also used a modified InfiniBand network, combining it with a specialized network for performing frequent tasks more efficiently. "In the end, we may see some new, efficient kind of Chinese switching that adheres to the InfiniBand standards," he says, adding that the Dawning's interconnect system is "very forward looking."

The designers of the processors were also prescient in the stress they've put on conserving power. "The race to exaflop computing will be a race to energy efficiency," says Steve Scott, now chief technology officer of Nvidia's Tesla unit and formerly a senior vice president of Cray, a pioneering supercomputer company.

The Godson-3B, capable of 128 billion flops using just 40 watts, claims almost double the peak power efficiency of some U.S. competitors. At press time, however, the Godson's energy efficiency had yet to be tested using a standard benchmark like Linpack. And, Dongarra points out, the processor is only one part of an energy budget that also includes interconnects and memory. The BlueLight's complete system also turned heads with its efficiency. The system can perform 741 megaflops per watt, compared to 636 Mflops/W for the Tianhe-1A, Dongarra says.

Researchers at the Chinese Academy of Sciences are already upping the efficiency of the next class of processors, the Godson-3C. According to one of the chip's architects, Yunji Chen, the 3C will have an even higher performance-to-power ratio, mainly because the processor will be built using a 32-nanometer fabrication process as opposed to the 3B's older, 65-nm process and because the new chip will feature an improved three-level cache memory.

Even more energy could be saved by moving from CPUs to GPUs, as other high-performance computers have done. Such graphics processing chips—now used in general computing—can do simple operations on great gobs of data in parallel, rather than in a more one-at-a-time fashion as a CPU core does. That parallelism economizes on energy. Nvidia's Scott says that an Intel Westmere CPU takes about 1.7 nanojoules per operation at peak performance, while an Nvidia Fermi GPU takes less than a seventh of that. Though China has produced some homegrown midlevel GPUs, the Chinese Academy of Sciences appears to be focusing its efforts on the Godson line of CPUs.

But favoring CPUs may just be another part of China's strategy, says El-Ghazawi. He notes that it isn't nearly as easy to program for GPUs, and Chinese supercomputer makers are looking not merely for speed records but for market share. "Although they are a latecomer," he says, "they are really hitting the ground running." ❑

Chinese Supercomputers

Supercomputer	Developer	Debut in Top500	Processors
Tianhe-1A	National University of Defense Technology	November 2010	Nvidia Tesla GPUs and Intel Xeon CPUs with custom interconnect
Sunway BlueLight MPP	National Research Center of Parallel Computer Engineering and Technology	November 2011	ShenWei SW1600 CPUs with an InfiniBand QDR interconnect
Dawning 6000	Chinese Academy of Sciences and Dawning Information Industry	June 2012 (expected)	Godson-3B CPUs

Geothermal & Coal Power Together

2012 TECH WATCH

The aptly named geothermal energy company Hot Dry Rocks will soon demonstrate a potentially powerful twist on this technology. By the end of the year the Australian enterprise plans to start up a plant that draws its power from heat trapped underneath an insulating coal bed.

PAUL TEBBOTT

IEEE spectrum Previous Page | Contents | Zoom in | Zoom out | Front Cover | Search Issue | Next Page
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TOP TECH 2012

TOO, TOO SOLID The robots [above, at left] are from My Robot Nation; the movable concentric rings (created that way—no assembly required) and the folded-over bicycle chain are from Stratasys; the gold-plated metal matrix and the glazed ceramic vase [right] come from Ponoko. PHOTO: RANDI SILBERMAN KLETT

TAKING SHAPE

This year, 3-D printing will go from prototyping to production

BY PAUL WALLICH

The promise of 3-D printing is tantalizing: You envision something, draw it with the right software, and then print it in three dimensions—regardless of how many parts it has, how they interlock, or whether they will even be accessible once your creation is completed. With this strategy, anyone can make almost anything. Someday, lots of stuff will be manufactured this way, on demand.

Full realization of that promise remains a long way off, but the bandwagon is rolling. Thousands of machines, ranging from kit-built tabletop models to commercial behemoths capable of printing the body of a small car, are out in the world producing parts. And starting this year, the United States' Defense Advanced Research Projects Agency is planning to put 1000 production-quality 3-D printers in high schools across the United States as part of its Manufacturing Experimentation and Outreach program. Even if you don't have access to one of those machines, you can get a free download of Autodesk 123D, a 3-D computer-aided-design program still in public beta testing, which gives you push-button connections to online 3-D–printing services, of which there are now dozens, if not hundreds. So if you're not already printing objects on a regular basis, there's a good chance that in 2012 you will be.

Many 3-D–printed objects are used behind the scenes in the production of something else. Jeff DeGrange of Stratasys, a manufacturer of 3-D–printing machines in Eden Prairie, Minn., came to the company after 20 years in manufacturing R&D at Boeing. So when asked where 3-D–printed parts are being used, he naturally offers as an example aircraft companies that print assembly-jig inserts for holding wing sections and other parts in place for drilling and fastening. He says the companies that manufacture high-performance cars have also begun 3-D–printing molds for carbon-composite panels. Machining or sculpting the complex curves required for these body panels is far too time consuming and expensive to do any other way.

Meanwhile, dental laboratories are using 3-D printing to help fabricate crowns and bridgework, metalworking companies print molds for casting jewelry and other small objects, and small-aircraft manufacturers, such as Piper, have even found that 3-D–printed dies can serve for stamping aircraft parts out of sheet metal. The applications go on and on.

What all these examples have in common is the high cost of conventional production of parts used for tooling or machining. Injection molds can cost thousands or tens of thousands of dollars for a single design, so it often makes sense to spend even hundreds of thousands for a production-capable 3-D printer that can churn out many different plastic shapes with ease. Plastic parts produced by fused-deposition-modeling machines (which spit out liquid plastic to build up the desired geometry) typically have about two-thirds the strength per unit area of injection-molded plastic parts, but that's just fine for most applications.

1867

First patent granted on inkjet printing, to William Thomson (later Lord Kelvin)

If you don't work in one of a relatively few forward-thinking industries, you're more likely to get or give a 3-D–printed object as an artsy gift than to use one for practical purposes. Scott Harmon of Z Corp., in Burlington, Mass., explains that digital art is a significant part of the market for his company's machines and those of some other manufacturers. Z Corp.'s powder-bonding technology, with binder-spraying cartridges and heads based on ink-jet printers, can make full-color objects simply by adding pigments to the binding liquids.

Having multiple colors is nice for distinguishing the working parts in models of mechanical devices, and it's essential for many other products. As examples, Harmon cites among other items bobble-head dolls, heroic statuettes of computer-game players' alter egos from *World of Warcraft* (at FigurePrints), and design-it-yourself 1950s-style robot figurines at My Robot Nation. If you want digital art that's more elaborate than what you can think up on your own, there are 3-D–printing services, such as Shapeways and Ponoko, that should delight you. Select an object from their online galleries or send them a design file and some money, and they'll send you the thing printed in plastic, sintered metal, or glazed ceramic.

If you just have an idea, you can turn it into the appropriate digital file using Autodesk 123D or any of a handful of other free or low-cost 3-D design programs. For those who want to work on their own designs entirely in the cloud, there's Tinkercad, a simple but still useful program that operates entirely in a browser and has a button for sending the completed design to Shapeways or i.materialise. And if you'd prefer to design something involving shapes based on mathematical functions, there's OpenSCAD, an open-source solid-geometry app that lets users write programs to combine geometric primitives like spheres and cylinders.

For many people, the age of 3-D printing has already arrived. For others, it's still in the future but getting nearer every day. If you're one of the latter group, 2012 would be a good year to learn how to print objects. Even a company that can't yet make money from this technique might want to get a feel for it now rather than try to scale the learning curve after its competitors have done so. ❑

A 3-D–Printing Bestiary

There are endless variations on how to print in three dimensions. Most devices fall into two main categories—extruders and consolidators. An extruder squirts a liquid out of one or more nozzles so that the liquid solidifies, layer by layer, to build up the desired shape. A consolidator spreads a thin layer of some easily removable substance over the build platform, creates bonds at particular spots on that layer, lowers the platform, spreads another thin layer on top of the one that was just processed, and repeats. At the end the unconsolidated material is removed.

EXTRUDERS

- RepRap, MakerBot [left], and all the other **home-built 3-D printers** typically have only one nozzle.
- **Turnkey printers** from Stratasys and others typically have a primary nozzle and at least one additional nozzle for printing removable material to support overhangs.
- **Inkjet-style extrusion printers** such as Objet Geometries' PolyJet spit out instant-curing polymer. Envisiontec's 3-D Bioplotter extrudes biomaterial.
- Extruders for **ceramics and cements** include a modified MakerBot and RepRap, and at a much larger scale, Contourcraft's concrete-wall builder.

CONSOLIDATORS

- Selective **laser-sintering machines** [EOSINT P380i model, right] fuse plastic or metal powders. The powder acts as a support while parts are being printed. It allows for overhangs and even free-floating parts to be entirely contained within the main structure.
- **Electron-beam metal-melting machines** operate under a vacuum to weld metal particles into a solid mass. The results are stronger than those made by sintering metal particles.
- **Powder-bonding printers** use inkjet technology to shoot droplets of a bonding agent onto various powders.
- **Photo printers,** such as Envisiontec's Perfactory line, use short-wavelength light to polymerize various liquid plastics, either for direct use or as sacrificial molds for casting metals. As with the two-nozzle extruders, supporting material can be printed and then removed.

TOP: MAKERBOT; BOTTOM: ENTERPRISE CONNECT


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Applicants should please write "Application for Electronic Devices" on the submission envelope.

ieee spectrum Previous Page | Contents | Zoom in | Zoom out | Front Cover | Search Issue | Next Page Qmags THE WORLD'S NEWSSTAND®

the data

Data Mining Scrabble

CHESS had its Deep Blue. "Jeopardy" had its Watson. Baseball has its sabermetrics, as chronicled in the hit book and film *Moneyball*. In each game, data mining has upended the field of play. And now the same big-league technologies are about to hit Scrabble.

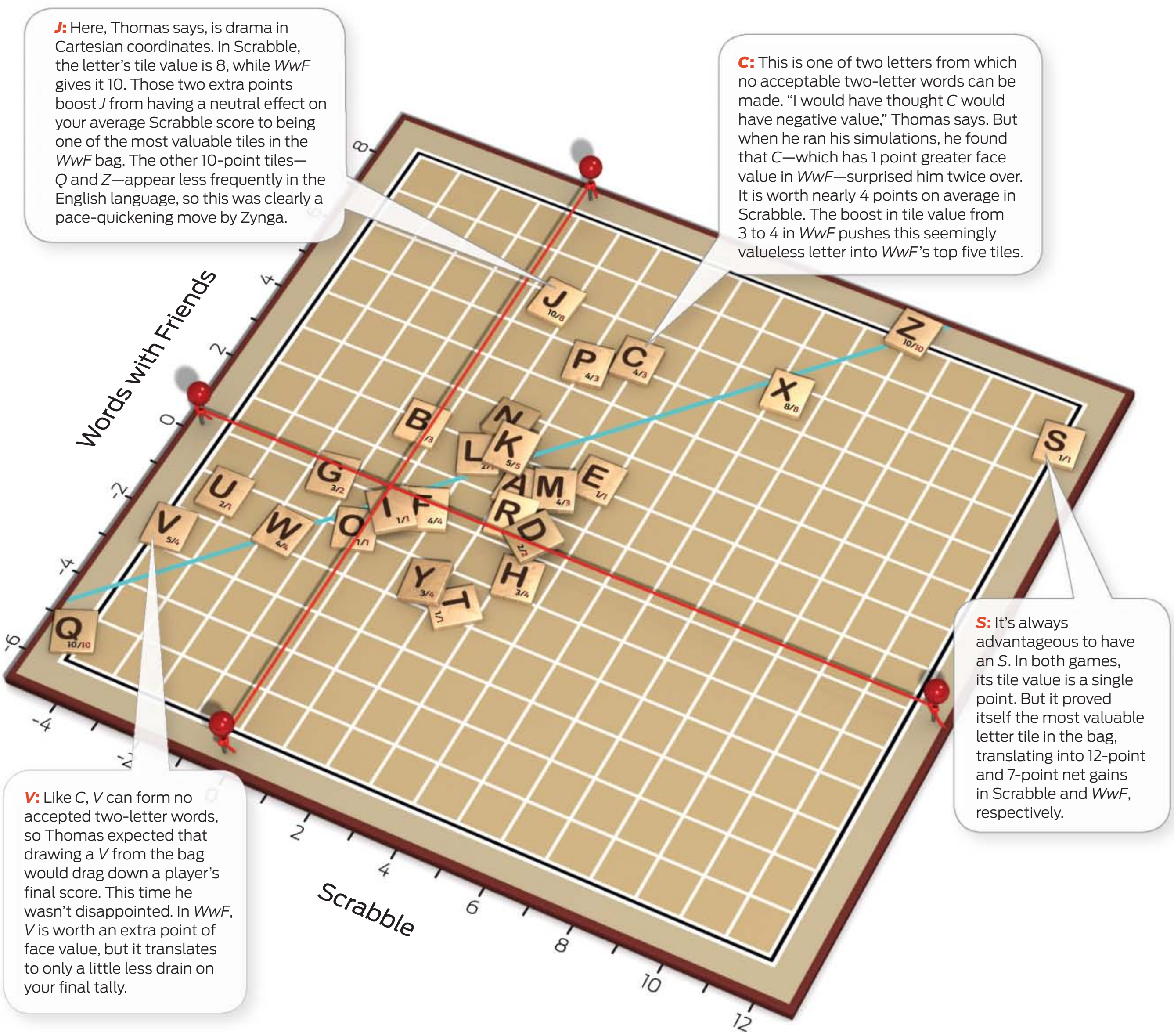
Using an open-source artificial-intelligence crossword game program called *Quackle*, Andrew C. Thomas, a visiting assistant professor of statistics at Carnegie Mellon University, in Pittsburgh, ran nearly 10 million simulated games to discover which Scrabble letter tiles confer the most value to a player.

As you might have suspected, *Q* is bad news. Yes, its tile value is 10 points, but Thomas's stats show that having a *Q* in your rack brings your game's final score down by 4 on average.

In the Facebook game *Words with Friends*, a sort of Scrabble derivative [see "Not Your Parents' Scrabble" in this issue], tile benefits, as well as values, differ dramatically. *WwF*'s maker, Zynga, has laid out a board that encourages explosive plays and upset victories, in part by upping the point value of 12 letters and downgrading 2 others.

Comparing the average merits and demerits of each letter in simulated matches of Scrabble and *Words with Friends* will confirm some player intuitions and call others into question. Is getting a *G* generally a bad thing? Is *M* better than *F*? And will the letter *Q* ever recover from Thomas's findings? —*Mark Anderson*

SOURCE: Andrew C. Thomas



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