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FOR THE TECHNOLOGY INSIDER | 01.13

Through A Glass Smartly

GOOGLE GLASS IS JUST ONE OF 22 TECH BREAKTHROUGHS THAT WILL MAKE NEWS IN 2013

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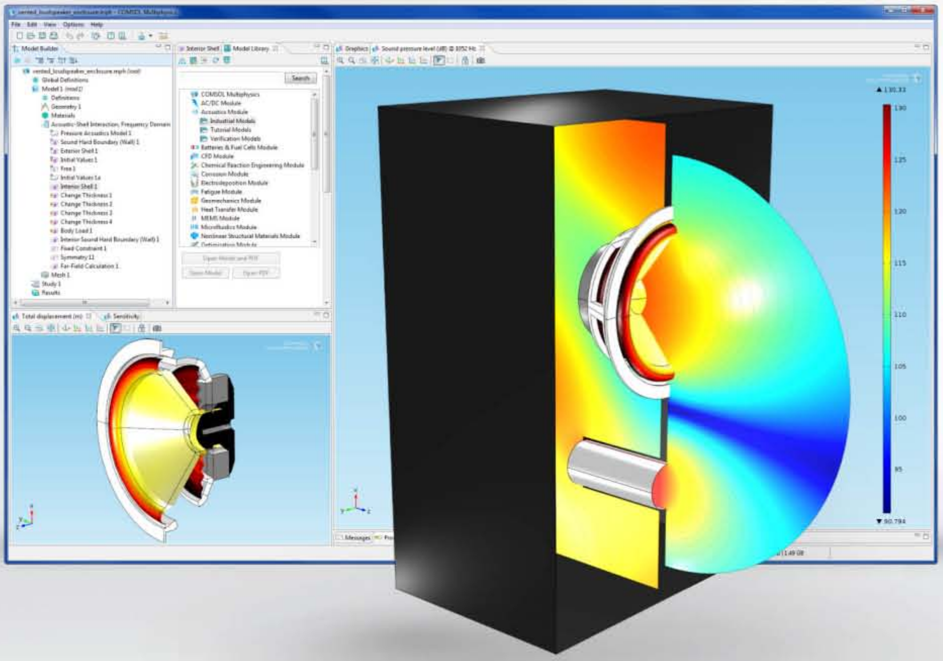

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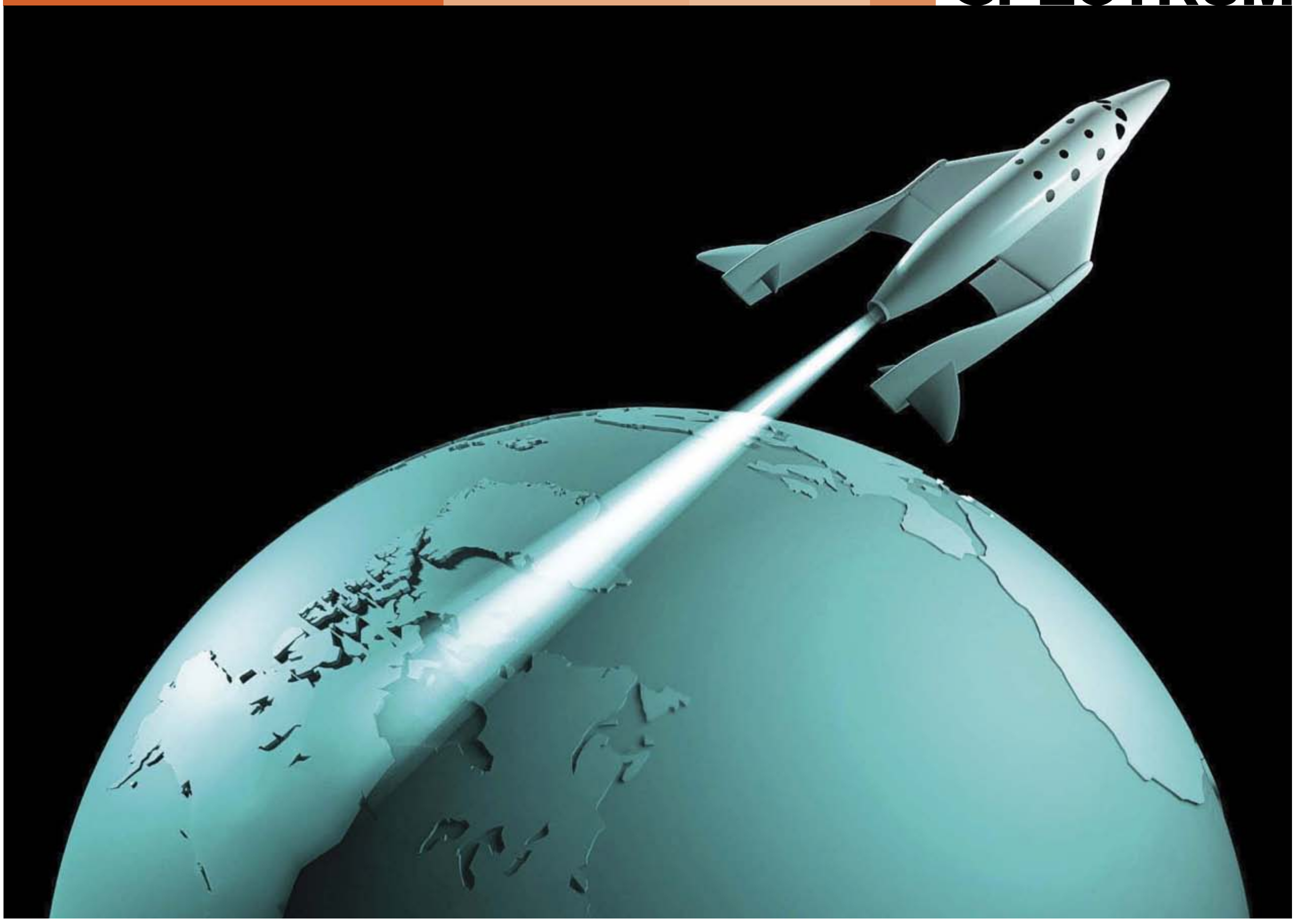

2013 TECH TO WATCH

23 "Prediction is hard, especially about the future," said either baseball legend Yogi Berra or physicist Niels Bohr (or both). We take on the challenge by previewing this year's tech news so you'll be ready for commercial space travel, a map of the cosmos, even a computerized doctor.

On the cover and above **Illustrations for IEEE Spectrum by Eddie Guy**

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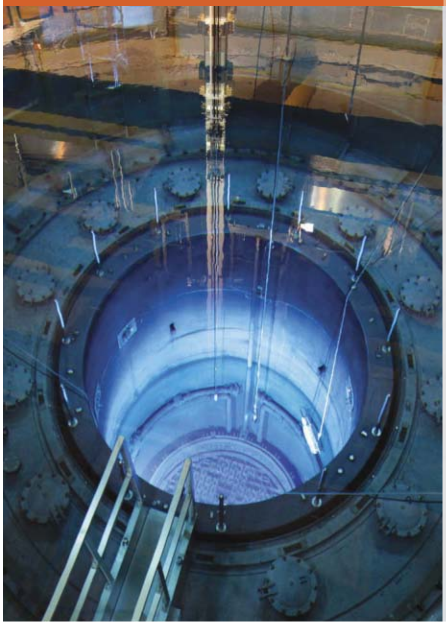

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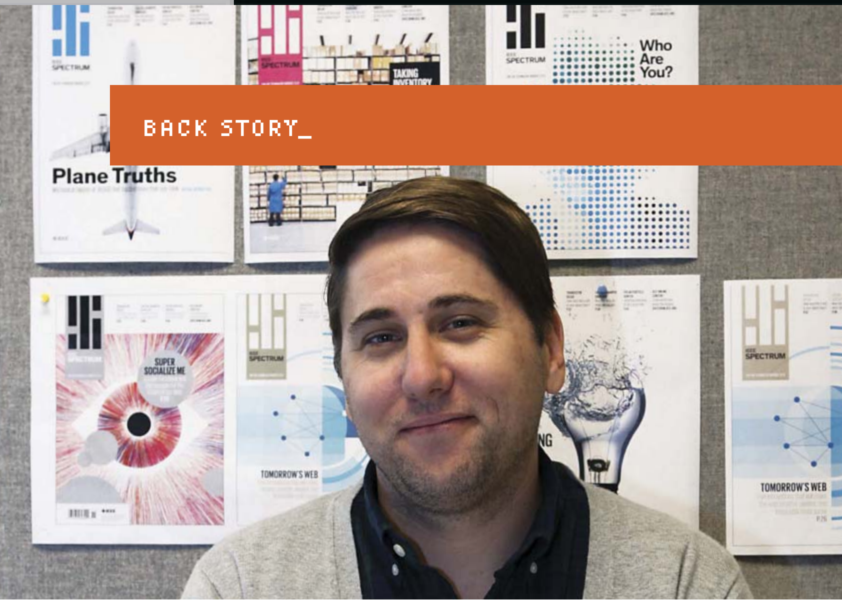

BACK STORY_

The Man With Designs on Us

Fourteen months ago, when we went looking for a designer to redesign the print edition of *IEEE Spectrum*, Senior Art Director Mark Montgomery considered candidates very carefully. In the end he chose Oakland, Calif.-based Carl DeTorres, and in this issue you will see the results of that choice.

Growing up in Southern California in the 1980s, DeTorres became hooked on books about space travel, robots, architecture, and other tech-sci subjects. He especially loved the diagrams, and in time, it turned out that his natural talents ran more toward art than math. After getting a bachelor's degree at the California College of the Arts, in San Francisco, he worked for four years as an art director at *Wired*.

In redesigning *Spectrum*'s print edition, DeTorres worked closely with Method New York, the firm that was in the process of redesigning *Spectrum*'s website. Out of that collaboration came *Spectrum*'s new, iconic logo, the big, striated "S" you see in the upper-left-hand corner of this month's cover.

The logo project began going in that direction during a meeting at Method's offices in lower Manhattan, when DeTorres asked, "Have you ever seen a chart of the radio spectrum? It's really beautiful." That got the Method people thinking. In the "S" logo they designed, the striations represent different frequency bands. When they first showed the logo to DeTorres, his reaction was immediate. "I thought: Perfect," he says. "They nailed it."

DeTorres arrived at our office on a brisk, bright October day to present his final templates. The next day, after many exhausting meetings with art directors and editors, he stole away for a lunchtime break. His destination was a gallery with a load of vintage technology posters by one of his heroes, the illustrator Erik Nitsche. A couple of hours later he returned with three of Nitsche's works.

Even on days when he hasn't found graphic-arts treasures, DeTorres's upbeat demeanor can be infectious. "I love my work, because I get to learn about things all the time," he says. "What more can you ask for in a job?" ■

CITING ARTICLES IN IEEE SPECTRUM *IEEE Spectrum* publishes an international and a North American edition, as indicated at the bottom of each page. 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, Dataflow is in *IEEE Spectrum*, Vol. 50, no. 1 (INT), January 2013, p. 64, or in *IEEE Spectrum*, Vol. 50, no. 1 (NA), January 2013, p. 80.

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Elise Ackerman

An editor for the cloud communications company Twilio, Ackerman writes in this issue about Google's new smart glasses [p. 24]. She started covering the company in 2006, the same year she had Lasik eye surgery. Could Google Glass convince her to wear glasses again? "The enthusiasm of proponents is contagious," Ackerman says. "But to go back to glasses, I'm going to need a killer app."

Katherine Bourzac

A freelance writer based in San Francisco, Bourzac hunted down analysts and academics to find out whether Intel, known for its high-performance chips, might transform itself into a fleet-footed mobile contender ["Intel Inside. . .Your Smartphone," p. 54]. The investigation gave her a new appreciation for the technology behind today's smartphones, she says. "It also convinced me it might be time to get a new one."

Peter Fairley

Newfangled energy ["Greening Canada's Tar Sands," p. 30] and ways of conserving it ["Auto Giants Bet Big on Mini EVs," p. 29] are Fairley's beat, which he covers as a globe-trotting freelancer from bases in Vancouver Island and Paris. An *IEEE Spectrum* contributing editor, he wrote about the costs and benefits of solar power in Spain for our September issue.

Eddie Guy

Guy says he is thrilled to work on the first issue of *Spectrum*'s redesign. He collaborated with our creative team to create the powerful graphics both inside the magazine and on its cover. In his free time, Guy channels his energies into martial arts. He can fight with the bow staff and the long, curved kukri knife, and he holds a red belt in karate.

Vinod Sreeharsha

An American journalist based in São Paulo, Sreeharsha covers politics, economics, technology, and entrepreneurship in South America. He has written for *The New York Times*, *The Miami Herald*, and *VentureBeat*. Sreeharsha, whose article in this issue focuses on cellulosic ethanol [p. 52], says he relocated to Brazil because it's "a deeply complex nation—the more you learn, the more you realize you don't know."

Chris Thompson

Thompson, a freelancer, used to write Slate's Feeling Lucky blog, which covered Google. In 2009 he noted that Google's bosses' efforts to digitize the world's books had created "intellectual property problems that no one thought they ever would have to address." In "Read Free or Die" [p. 50], he describes a new nonprofit attempt led by Harvard University to solve those problems.

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PHOTO-ILLUSTRATIONS BY **Gluekit**

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Our Annual Crystal Ball Issue

In the 1944 movie *It Happened Tomorrow*, a newspaperman, played by Dick Powell, gets a magical edition of the next day's newspaper. He scoops the competition, amazes his editor, saves a damsel in distress, and becomes a hero, only to get an early look at the ultimate story: the report of his own death. ¶ It's the classic nightmare of seeing the future without being able to change it, and it goes all the way back to the Arabian merchant's appointment in Samarra and to Oedipus's fateful flight to the city of Thebes. But for an engineer, the horror is to see the future without *understanding* it.

We at *IEEE Spectrum* can't change the future or even predict it in any privileged way, unless you count our rare privilege of receiving tips from our board of advisers and our astute readers. What we can do, though, is preview the coming year's technology projects–those whose launches have been announced or rumored but not fleshed out.

Our job is to put meat on those bones. That way, you won't suffer the agonizing embarrassment of being caught by surprise when somebody mentions the tech headline of the day. With this issue, we send you out to the cocktail parties of the world armed to the teeth with knowledge. Your job is to perfect a knowing smile.

"Cellulosic ethanol conversion?" you could say, your face brightening slowly. "Weren't the Brazilians supposed to start that up this year? Of course, first they had to get some really good cellulolytic enzymes...."

"Gaia?" you might murmur, as if searching your memory. "Oh, yes, the Europeans were going to put it at the second Lagrange point–avoids ducking in and out of the Earth's shadow and the resulting thermal expansion. Plays havoc with the instruments, you know."

"Great, so Google's new visor is coming out," you could pronounce, dryly. "But when did you last say to yourself, 'The real problem with Google is it's too far from my face'?"

Or maybe someone mentions Intel's secret Silvermont project. You set down your glass very firmly. "Well, it's about time that company got serious about low-power chips," you intone. "It's not as if the mobile market is just a niche, good for nothing better than Intel's stripped-down standard processors–power hogs, I tell you."

Unlike the movie's spooky newspaper or Oedipus's far-seeing oracle, *Spectrum* can't be considered right all the time. When we do err, though, we generally err on mere timing. For instance, we predict that commercial passenger flights into space will begin this year–just as we said it would last year [see "Private Spaceflight: Up, Up and Away," January 2012]. No worries: You can simply say, "Yes, Virgin Galactic's had a few bumps in the road, haven't they? *Spectrum* originally said they'd start service in 2012...."

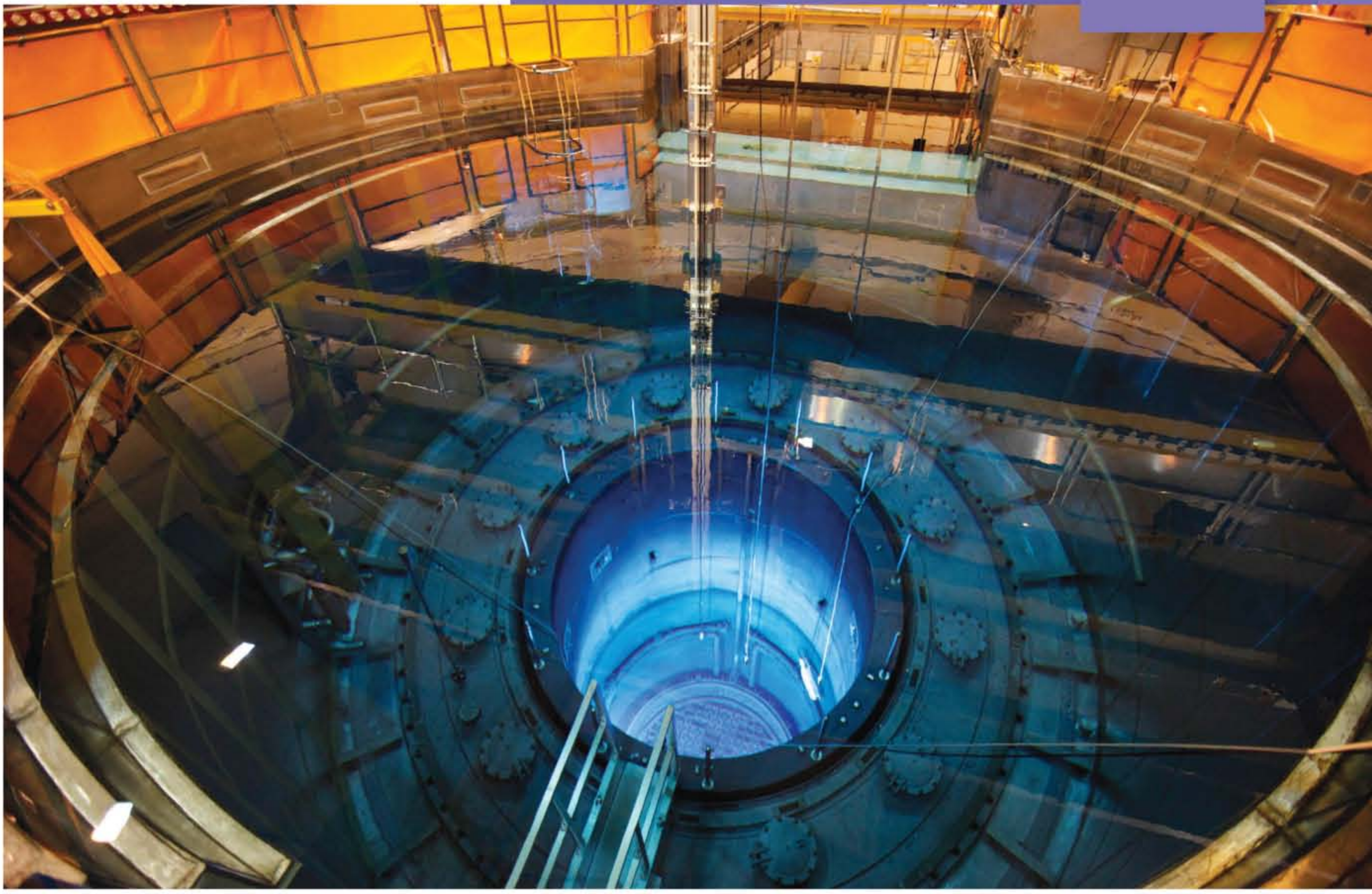
Go ahead: Take credit when we're right and blame us when we're wrong. We can take it. Criticism builds character. –PHILIP E. ROSS

CORRECTION In the illustration label for "Dancing With the Stars" ("Overclock My Satellite," November), the satellite's typical smallest-angle path took 877 seconds to complete, not 887.

PHOTO-ILLUSTRATION: GLUEKIT; SOURCE: IPHOTO/GETTY IMAGES

NEWS

THE NUCLEAR INDUSTRY PRODUCED 10 500 METRIC TONS OF SPENT FUEL IN 2011



A FISSION-FUSION FUSION

Could a marriage of fusion and fission reactors save both technologies?

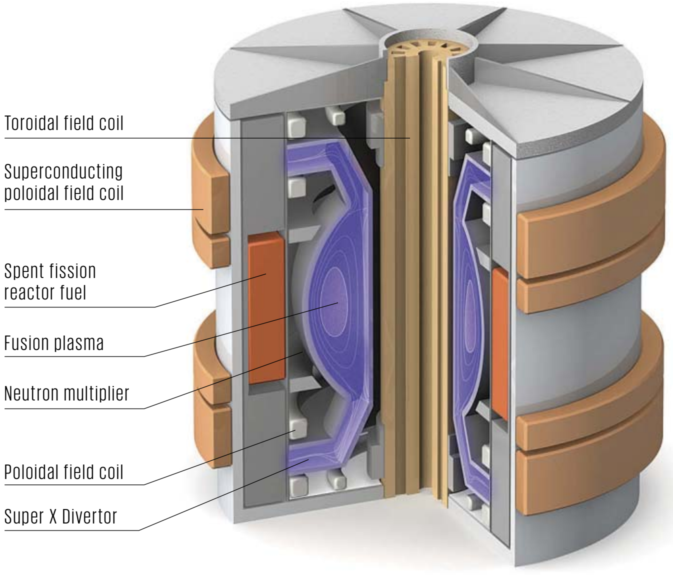
BY WILLIAM SWEET

FUEL POOL: A fusion generator could make the fuel rods removed from this fission reactor safer to store.

RUBEN SPRICH/REUTERS

What if you could help solve the nuclear waste problem and at the same time give fusion research a new raison d'être? A trio of physicists at the University of Texas at Austin have dreamed up a trick to pair nuclear fusion and fission in a way they think could open more promising futures for both technologies.

Their idea is to surround a compact, circular tokamak fusion reactor they have devised with a ring containing the most noxious waste products from nuclear power plants. Neutrons emanating from the fusion reactor would break down long-lived transuranic radioactive wastes from spent fuel and turn them into much shorter-lived elements. The net effect would be to convert high-level radioactive wastes containing elements like americium and curium, which need to be stored safely for 100 000 years or more—a problem that has derailed big storage projects like Yucca Mountain—into fission products, such as barium, that fully decay in hundreds of years.



TRANSMUTING TOKAMAK: Toroidal and poloidal magnetic fields compress a deuterium and tritium plasma until it fuses, releasing a dense shower of neutrons, charged particles, and unburned fuel. The neutrons smash into a blanket of spent fission fuel that surrounds the fusion reactor, transmuting the more dangerously radioactive elements in the spent fuel into shorter-lived isotopes. Meanwhile, the hot unburned fuel is swept away by the Super X Divertor.

But this scheme wouldn't work unless scientists and engineers could come up with a neutron source that was simultaneously intense and compact. A source like that would have its own waste disposal problem: The plasma core would emit heat and a flow of particles so intense they would destroy the machine.

In a standard tokamak, magnetically confined deuterium and tritium fuse in a plasma, releasing neutrons, electrons, and alpha particles (helium nuclei). The magnetic field lines confining the plasma consist of open regions—where the lines penetrate the reactor—and closed regions, where they form self-contained ovoids. At the so-called X-point where the lines are open, the plasma can be tapped to let unburned ions escape, transferring their heat to a metallic plate. The rub is that in some tokamaks, that concentrated stream of plasma would melt any conceivable plate.

The Texas team of researchers—Swadesh Mahajan, Mike Kotschenreuther, and Prashant Valanju—came up with the idea of redesigning the fields to broaden the X-point and channel the ash stream into a divertor, where they would place a second X-point well away from the main plasma. Fanning out from the second X-point, the wider waste stream would be able to transfer 5 to 10 times as much heat, or 10 megawatts of heat per square meter.

This design, called the Super X Divertor, will be put to the test as a centerpiece of a £30 million (US $48 million) upgrade to the MAST, or Mega Amp Spherical Tokamak, at the Culham Science Center in Abingdon, England, according to the center's CEO, Steve Cowley.

The researchers at Culham aren't really interested in turning this tokamak into a spent fuel transmutation unit, but the 12-year-old fusion machine, when upgraded and operating again in 2015, will be similar to such a unit. In the transmutation scheme, a modular spherical tokamak is surrounded by a blanket of spent fuel rods. The physical arrangement is rather like that of a standard fast-breeder reactor, in which neutrons emitted from a core of plutonium or highly enriched uranium are captured in a blanket consisting of nonfissionable uranium-238, which transmutes to fissionable plutonium. The Super X Divertor will make it possible to design and build a tokamak compact enough to emit the dense cloud of neutrons needed to transmute nuclear wastes.

> The ITER fusion device now under construction will exceed 5000 metric tons. A hybrid fission-fusion reactor would weigh less than 700 metric tons.

For the record, the Texas team is not the first to propose using fusion-generated neutrons to chop the half-lives of fission wastes. Ideas for fission hybrids have been kicking around since the 1950s. Several years ago, Weston M. Stacey of Georgia Tech came up with what Mahajan calls the "canonical concept" for a hybrid in which a fission reactor would be embedded inside a large tokamak, a vision Stacey calls the Subcritical Advanced Burner Reactor.

Separately, the Nobel Prize–winning physicist Carlo Rubbia has talked up the idea for two decades of having protons from an accelerator bombard a target, knocking off neutrons, which in turn do the work of fracturing transuranics. A test of that approach began last January, at the Belgian Nuclear Research Centre, in Mol, when an accelerator and reactor were linked for the first time.

An obvious problem with Stacey's hybrid is how to implant and remove fuel from—not to mention maintain—a fission reactor that is surrounded by a tokamak generating hugely energetic plasma fluxes. The obvious problems with accelerator-driven systems, says Mahajan, are their relatively unattractive neutron economics and the rather Rube Goldberg–esque sense of the overall system design.

But the Texas approach also could look increasingly like one of Goldberg's mad engineering drawings as the specific details are fleshed out. For example, for the transuranic waste to be fully converted to shorter-half-life elements, three stages of fuel reprocessing would be required, with extracted elements reinserted into the tokamak blanket for further fissioning. Right now only the Super X Divertor is a well-developed design. ■

ILLUSTRATION BY Emily Cooper

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3-D TRANSISTORS FOR ALL

Nearly two years after Intel, the world's leading foundries rush to get FinFETs into the hands of chip designers

The 3-D transistor is poised to go mainstream. After falling behind Intel, the world's biggest foundries are all gearing up to produce these cutting edge switches. And to accelerate the process, some have opted to take an unusual step: marrying the new transistors with an older approach to building the wiring that ties them together on a chip.

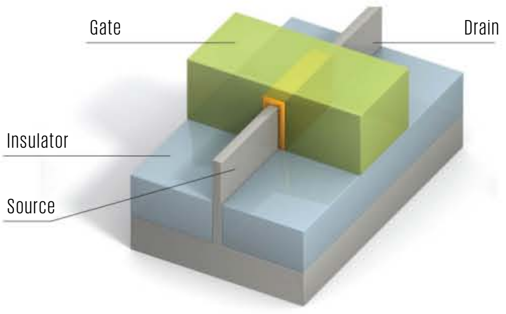
The hope is that this hybrid strategy will help foundries make 3-D transistors, or FinFETs, available to most of the world's semiconductor firms by 2014, a good year earlier than anticipated. That could help close the gap with Intel, which unveiled the first commercial 3-D transistor process in 2011 and likely aims to supply the technology, with few exceptions, only to itself. Intel plans to release the transistors in smartphone and tablet chips tailor-made to compete against the foundries' customers.

Chipmakers are switching to FinFETs because each time they have shrunk their ordinary, planar transistors, manufacturers have seen a smaller performance gain. FinFETs–which effectively turn the transistor's current-carrying channel on its side to create a fin–carry more current and leak less of it, making for circuits that perform better and use less power. GlobalFoundries, Samsung, Taiwan Semiconductor Manufacturing Co. (TSMC), and United Microelectronics have all made it clear that they plan to pursue the technology. They aim to introduce FinFETs at the 14-nanometer-manufacturing-process node–a step, more or less, behind Intel's 22-nm introduction.

To get there, both GlobalFoundries and TSMC have revealed they'll take a half step. They will replace planar transistors with a denser array of FinFETs, but they won't advance the manufacturing process used to build the wiring that connects the devices on the "back end" layers of the chip. As a result, although there will be more transistors in any given area, a good number of them won't be connected and therefore can't be used. The chips won't be much smaller than the 20-nm generation, which is going into production now. That means the foundries won't be able to create more of them on a single wafer to reduce costs. Nonetheless, GlobalFoundries expects the chips it will produce could be as much as 55 percent faster or 40 percent less power hungry than the 20-nm generation.

For GlobalFoundries, the advantage of this halfway approach is that it will let the company keep more than 7000 design rules that were developed for the 20-nm planar chip, while changing just 60 or so that are needed to describe the fin, says Subramani Kengeri, vice president of advanced technology architecture at GlobalFoundries. "First-generation FinFET is a huge challenge. There's no question about it," says Kengeri. "Adding more risks to that by adding other complexi-

NEWS



FINS ARE IN: Three-dimensional transistors, or FinFETs, control current between the source and drain more effectively by surrounding the transistor channel with the gate on three sides.

ties that were not necessarily fin-related was not prudent." All told, the hybrid approach should allow the company to accelerate production by a year.

TSMC, which calls its FinFET scheme a 16-nm process, says its chips are "similar" in size and density to other foundries' 14-nm offerings. Later this year, both TSMC and GlobalFoundries hope to create small batches of test chips for customers and are targeting full production in 2014, which will put the companies' releases more or less on the same schedule as that of Intel's own 14-nm chips.

"I think this incremental strategy is probably a very sound, safe way of not changing too many things at the same time and developing something they can be sure can be production worthy," says Chi-Ping Hsu, who heads up research and development for the Silicon Realization Group at Cadence, an electronic design automation firm based in San Jose, Calif.

FinFETs are "a huge challenge for the whole industry," Hsu says. He estimates that his team at Cadence has already spent some 4000 man-years overhauling computer code for today's generation of chips so that processor operation can be simulated in a realistic time frame. FinFETs, which boast stronger electrical effects on their neighbors and have dimensions that can't be adjusted, are an added challenge. Hsu reckons it will cost the foundries and their partners some US $6 billion to develop the manufacturing prowess and the computational tools needed to make 14-nm and 16-nm chips.

Whether the investment will pay off in the end is unclear, says Sam Tuan Wang, chief analyst for semiconductor foundries at Gartner. "People say if Intel can do it, I can do it. That's not true," he says. We may not have to wait long to find out.

—RACHEL COURTLAND

At the IEEE International Electron Devices Meeting in December, Intel claimed that its FinFETs for mobile chips were 22 to 65 percent faster than the previous generation.

AN INTERNET-INSPIRED ELECTRICITY GRID

Japanese consortium aims to transform the country's centralized grid into islands of interconnected cells

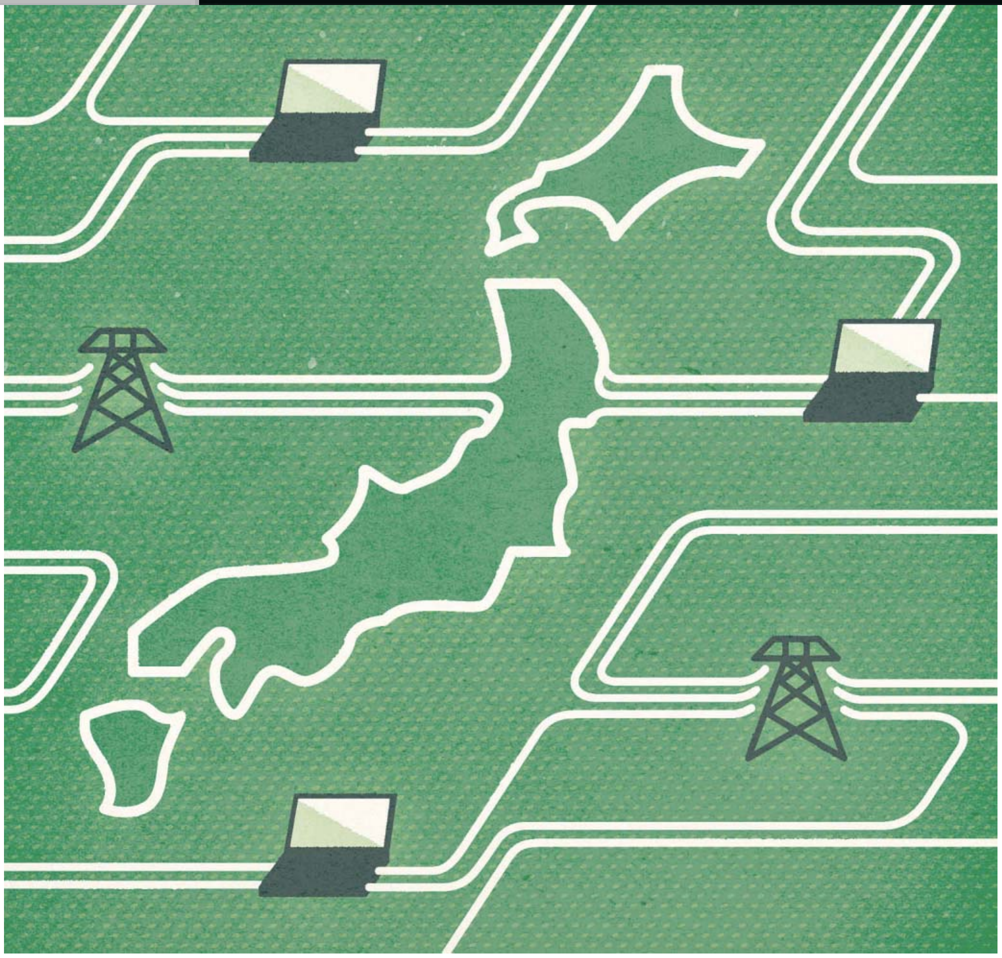
Japan's plan to phase out its nearly 50 gigawatts of nuclear capacity over the next two to three decades has opened a window for renewable energy in the country. But swapping wind and solar power for that nuclear generation, which produced 30 percent of Japan's electricity prior to the 2011 Fukushima crisis, could also lead to major disruptions in energy supply, warns Rikiya Abe, a University of Tokyo professor. The problem, says Abe, who came to academia after working in the electrical generation industry for 30 years, is that Japan's grid—and indeed that of many developed countries—is set up to be centrally controlled. The utilities have to carefully regulate the grid's frequency and voltage by maintaining a fine balance between power generation and changing demand. A diverse group of large Japanese firms is starting to explore a solution—a gradual reorganization of the country's power system so that in the end it resembles the Internet, routers and all.

"The present synchronized system has served us well," says Abe. "But when you introduce various sources of renewable energy, they will certainly increase fluctuations in the system, until at some point they become unmanageable." What we need, he says, "is a shift from central to decentralized control, with generated power being segmented and widely distributed."

The answer is what he calls "the digital grid," the architecture of which is based on the Internet. The idea is to gradually subdivide the existing synchronized grid into asynchronous, autonomous but interconnected cells of varying sizes. These assign the equivalent of IP addresses to generators, power converters, wind farms, storage systems, rooftop solar cells, and any other grid infrastructure within the cells.

"Theoretically it's sound; technically it's doable," says Paul Scalise, a former energy analyst who is now a research fellow at Temple University Japan and the University of Tokyo. "And it has the added benefit of dealing

ILLUSTRATION BY Emily Cooper



person, the cash need not be physically transported to complete the transaction. The actual communication in the digital grid is done primarily over the Internet, or in the case of power lines, by adding on a high frequency signal. "Each energy transaction will automatically be recorded and collected by certified service providers, along with additional properties such as location, time, generation source, price, and CO_2 credits," he says.

Since the 2011 earthquake, Abe says he's seen a great upsurge of interest in the concept, but he agrees that to turn the digital grid into a viable reality in Japan, he will have to win over the power utilities and major electrical equipment manufacturers, which so far have declined to join the consortium, "though we continue to talk with them and with METI [Ministry of Economy, Trade and Industry]," he says. "Eventually, they will have to accept the reality of renewably generated energy and [that] the present system is not set up to manage it," says Abe. "If they're going to remain key players in the coming renewable energy era, they really need to start changing their present business model."

with the renewable energy issue," he says. "So it's an idea that could hold sway with utility companies worldwide. The question is, though, who is going to pay for it?"

To get the concept off the ground, last September Abe established the Digital Grid Consortium, which he heads. To date it has six members: Hitachi Yokohama Research Laboratory, Kanematsu Electronics, National Instruments Japan, NEC, Orix Corp., and Sekisui Chemical. In the same month, Abe says, the group successfully demonstrated a key enabling technology—the Mark I, a 2-kilowatt, three-legged "digital grid router." DGRs would manage and regulate power demands by providing asynchronous connections and coordination within and between cells. The multilegged DGR comprises a solid-state AC/DC/AC converter using insulated gate bipolar transistors and other power electronics. These enable voltages to be raised or lowered on the fly as cell frequencies change, according to various demands. Early next year, the consortium plans to demonstrate two or more routers working together at the Knoxville, Tenn., Electric Power Research Institute test facility.

Equipped with a CPU, memory, data storage, and network communications, a DGR assigns tags (the equivalent of IP addresses) to discrete "packets" of power from various generated or stored sources that are sent into the grid, while receivers simultaneously extract the same amount of power from the grid. To illustrate how this would work, Abe gives as an example a cooperative residential group that puts in an order for renewably generated power at a certain cost. Using an Internet-based market mechanism similar to a stock exchange system for buying and selling securities, a broker locates a solar farm that accepts the order, and a contract is agreed on. "If the order is not matched, then there is no transaction," he says. "This maintains balance in the grid."

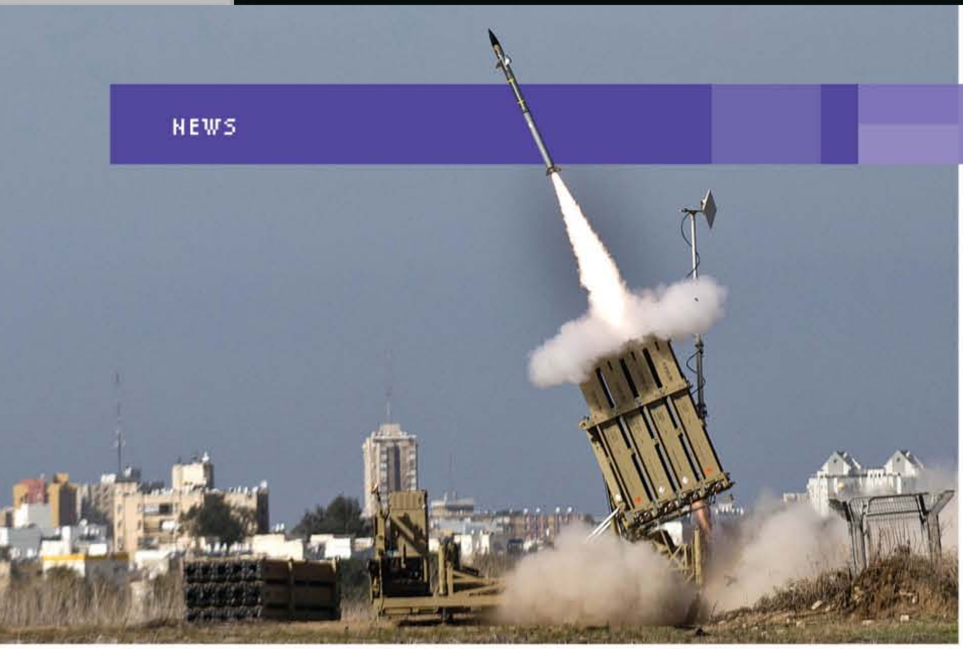
Abe likens the process to the banking system. If one person remits money to another

Scalise, author of an upcoming book on Japan's energy restructuring effort, agrees. "Any developed country moving towards a renewable energy portfolio will sooner or later have to deal with the transmission and distribution grid issue," he says. "And this is going to apply as much to the United States as it does to Europe."

In the meantime, the consortium is continuing to improve the DGR and has begun looking for opportunities to introduce the technology first in an underdeveloped country where countrywide grids don't exist. "In such countries...they may not even require a conventional grid system over the long run," Abe says. —JOHN BOYD

NEWS

ILLUSTRATION BY Jesse Lefkowitz



NEWS

SCORE ONE FOR ANTIMISSILES

Does the early success of Israel's Iron Dome system mark a turning point for missile defense?

Fifty years ago last month, U.S. president John F. Kennedy said that Nikita Khrushchev, the leader of the Soviet Union, had made an empty boast about his country's antimissile missiles. "What you are trying to do is shoot a bullet with a bullet," Kennedy said, coining an oft-repeated phrase. "Now, if you have a thousand bullets coming at you, that is a terribly difficult task which we have not mastered yet, and I don't think he has. The offense has the advantage."

Has Israel's Iron Dome missile system finally proved the case for the defense? In November, during a six-day barrage from Gaza, the system reportedly intercepted about 85 percent of the rockets its algorithms deemed worth shooting at.

Iron Dome is clearly a technical success, having done exactly what its designers intended. According to physicist Dean Wilkening, a missile-defense expert at Lawrence Livermore National Laboratory, the reported shoot-down rate is believable. "I don't think the Israelis will end up with egg on their faces the way the proponents of the Patriot antimissile defense did during the Gulf War." After the war, the Patriots were found to have been rather ineffective.

Some U.S. experts are even saying that the success heralds a new era for missile defense in general. But such a judgment requires weighing the wide-ranging costs and benefits of the system. By this way of thinking it could be argued that Iron Dome is hitting a bullet with a *golden* bullet.

The attacking rockets weren't the intercontinental ballistic missiles that concerned Kennedy, just unguided Qassams that could reach no farther than the cities of southern Israel, although a few Iranian Fajr-5 missiles did get as far as Tel Aviv and Jerusalem.

The Qassams miss their mark so often that it took an average of 300 of them to kill a single Israeli even before Iron Dome went into service, in 2011. But that's okay from the attacker's viewpoint, because the rockets scare civilians and cost less than US $1000 each, versus $50 000 to $100 000 for an Iron Dome interceptor. And even with the new defense system, Israeli civilians still had to run for cover during barrages.

The true cost also depends on scale. Back in the mid-2000s, Israel decided against two competing technologies, one of which, a U.S.-sponsored experimental laser system, would have been cost-effective only if it got the chance to destroy a lot of rockets. The laser would also have been cumbersome and subject to the vagaries of the weather. The Israelis also rejected Phalanx, an existing U.S. system based on rapid-fire guns, in part because of concerns about collateral damage if it were deployed in populated areas.

Nor can an antimissile defense be judged after a single outing; potential improvements must also be considered. The attacking side might fit its rockets with a basic guidance system, thus forcing Iron Dome to use up more of its expensive interceptors.

Better still, an attacker can defeat a defensive system by going around it. The Lebanese group Hezbollah, an ally of Iran's, may have tried just such an idea even before the latest exchange in Gaza. In October it sent an unmanned aerial vehicle from Lebanon down the Mediterranean coast to Gaza and then into Israel. There, according to Iran, it gathered valuable intelligence before Israeli jets could shoot it down. It would seem a small matter to load a flotilla of UAVs with bombs and steer them to their targets along varying routes, at low altitude.

Such criticisms, however, ask too much of any one weapons system, argues Wilkening. "Iron Dome is a simple system against a very rudimentary threat, and one should not draw too many parallels between it and long-range missile defense," he says. "But I think it shows that the technology is sufficiently mature and effective and that it's worth taking seriously."

The real test of Iron Dome's importance for missile defense is whether other countries end up buying it. There were stirrings even before November: The Pentagon has expressed interest in having Iron Dome coproduced in the United States, and a South Korean politician suggested the same arrangement in 2011, as did Indian military industry officials earlier this year.

—PHILIP E. ROSS

HOW IT WORKS

Iron Dome acquires its target with radars from a control center. In order to economize on interceptors, the system next judges whether the incoming rocket threatens a populated area. The control center targets the threatening rocket with a missile, guiding it only until the missile's own radar can lock onto the target.

JACK GUEZ/AFP/GETTY IMAGES

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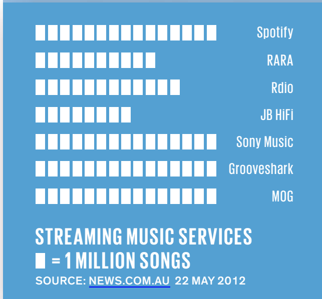
RESOURCES



RESOURCES_TOOLS

NETWORKED AUDIO PLAYERS BRINGING HI-FI INTO THE INTERNET AGE

Increasingly, the music we listen to is stored on our computers or streamed from distant servers. As a result it's now jumbled in with news, talk radio, and podcasts. Fortunately, a new generation of media hardware is bringing this sonic bounty to us. Here is a look at three very different networked audio players geared toward different needs, at different price levels and with varying degrees of complexity. ● If you're looking for something simple, Logitech's **UE Smart Radio** (US $180) is designed to be a stand-alone replacement for the traditional kitchen or desk radio. Its old-school front panel features a single speaker on the left and controls—including what looks like a large tuning knob—on the right. If not for the sharp 2.4-inch color screen and a few extra buttons, it could pass for a standard AM/FM radio. ● The Smart Radio is Wi-Fi and Ethernet capable, and basic setup doesn't require a host computer. Turn it on and it'll start looking for your network. You enter your password using the big rotary dial to select letters and numbers. ● The dial is also used to search for online radio stations by genre, location, language, or specific shows: WRUV, the university station in Burlington, Vt., popped right up when I looked for it. Once you find a station you like, store it as a favorite or press and hold one of the six preset buttons on the panel. The screen shows graphics from the selected station, along with the song title and artist. ● You can also install personal music-streaming services, such as Pandora and Spotify, but you'll need to use Logitech's website or its free iOS or Android mobile app to set those up. (Logitech's app also offers remote control of the Smart Radio.) A free app for your computer lets you stream your own music collection. Most file formats are supported, but iTunes songs encrypted with digital rights management (DRM) technology are not. ● A tap of the power button stops the music and displays a clock. The screen dims when ambient light is low so you can sleep. That is, until it wakes you by firing up your favorite station at one of the seven programmable alarm times. ▶

RESOURCES_TOOLS

UE SMART RADIO
Logitech

DNP720AE
Denon

PLAY:5
Sonos

Sound quality is surprisingly smooth and full for a box this size. With its class-D amplifier, long-throw woofer, and separate tweeter, the unit produces very pleasing monaural audio. Plug a cable into the headphone jack and the radio will feed analog stereo output to your entertainment center.

If you're looking for a way to add networked audio to an existing stereo system, consider Denon's **DNP720AE** ($500). It looks like a slim receiver or CD player equipped with a three-line monochrome organic LED display. Although it doesn't show graphics, the display does an admirable job of presenting the information you need to set up your network connection and make musical selections.

The unit incorporates FM stereo and AM tuners, offers analog and optical digital outputs, and lets you play music directly from an iPod or flash drive by plugging them into a USB port on the front. The Denon is Apple AirPlay compatible, so it will play DRM-encrypted iTunes songs directly.

Setting up the Denon was a breeze—nearly automatic, actually, after I screwed on the Wi-Fi antenna and turned the power on. I never even looked at the extensive manual and fold-out getting-started sheet. I just followed the onscreen instructions, hit the obvious buttons on the accompanying remote, and I was in. (The remote can also control streaming from your computer's iTunes library.)

The Denon's music options are like those of the other players, including the ability to select stations by location, and there's a wide choice of genres. Once you attach a network audio player to full-size speakers, audio quality is critical, and the Denon delivers. Even the 128-kilobit-per-second stream from my local classical station sounded artifact free and better than anything I've ever heard on FM.

Younger music fans probably don't even own a stereo system, and the Sonos **Play:5** ($400) is aimed squarely at this "I'm never without my phone or tablet" demographic. The Play:5 has only three buttons: two for volume and one for mute. You don't even need those, because all functions are controlled from your mobile gadget. This approach provides great flexibility, but you'd better have that phone with you.

A Play:5 can connect to a router via Ethernet, which can cause problems if you don't have easy access to the router. Wireless connectivity is provided via the Sonos Bridge, an optional $50 component that plugs into an existing router to create a separate mesh network (but of course you still need to get access to the router at least once).

This approach lets Sonos dedicate separate bandwidth to high-quality music playing. It might not seem as though music would bog down a Wi-Fi network, but the Sonos system lets you stream different music to multiple Play:5 units, so the bandwidth can add up.

The Play:5 is larger than a typical table radio but still nowhere near the size of a standard shelf stereo system. It's an attractive unit that incorporates a class-D amplifier for each of its five speakers: two tweeters, two midrange speakers, and a subwoofer. While it's not a full-blown audiophile stereo system, it projects powerful, rich bass and crisp treble, and it can get loud enough to drive you out of the room. If you want a wider stereo image, you can configure two Play:5 units as left and right speakers. The remote-control approach makes it easy to put your Play:5 in the rafters or atop a bookshelf, since you'll never have to touch it once it's paired to the Bridge.

The core of the Sonos system is its control software, available on computers and mobile devices. Anyone who has used an MP3 player app should experience the gentlest of learning curves. And yes, you can set wake-up alarms.

The music sources are pretty much the same as with the Logitech system: Internet radio, streaming services, and your personal collection, with most file formats (except DRM-protected iTunes) supported. Lots of streaming services are preloaded here; all you need to do is sign in. The Sonos Play:5 and Bridge system is well thought out and a delight to use. For many people, especially for those with a phone always in hand, Sonos may be the preferred alternative.
—MICHAEL JAY GEIER

Michael Jay Geier reviewed pocket oscilloscopes in our March 2012 issue. He's the author of How to Diagnose and Fix Everything Electronic *(2011, McGraw-Hill/TAB Electronics).*

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RESOURCES_PROFILE

ADRIAN CHEOK: MAKING A HUGGABLE INTERNET

AN INVENTOR BUILDS GEAR TO TRANSMIT TOUCHES, TASTES, AND MORE

CREATIVE COUNSEL: Adrian Cheok wants engineers to tap into their imaginations more, even if the results can seem a little strange.

GRADUATE SCHOOL OF MEDIA DESIGN/KEIO UNIVERSITY

Adrian David Cheok, the first person to hug a chicken via the Internet, has advice for creative engineers trying to make their mark. Rule one: Embrace your idiosyncrasies. Rule two: Get your hands dirty. Rule three: Don't worry about the critics.

His 2005 Poultry Internet project showcased all these strategies. Cheok, then an associate professor of electrical and computer engineering at the National University of Singapore, was fascinated by the notion of transmitting sensations over the Internet. He decided to start with haptics, the technology of touch, by building a system that would let pet owners remotely send their lonely animals a pat.

Growing up in Adelaide, Australia, Cheok had often played with his grandfather's chickens, so he decided to focus on poultry (rule one). He built little jackets for the chickens himself (rule two), embedding them with vibrating elements. Tinkering taught him just how difficult it is to produce a gentle, humanlike touch. "The system develops as you build it," Cheok says. "I see research as iterative—you're learning from what you're making."

The chicken's jacket was connected wirelessly to the Internet, and its coop was rigged with a webcam. Then, in his office, Cheok patted a chicken doll that had touch-sensitive sensors, and the squeeze was transmitted to the live bird while he watched. The chicken had been hugged.

Cheok says some of his colleagues weren't impressed: "There were some of the faculty who thought, this is not engineering, let alone research," he says. But he persisted (rule three) and found appreciative audiences at both international conferences and in the coop. (In an experiment with a flock of chickens, 70 percent chose to enter the room where their jackets would be put on them instead of a room where they'd be left alone.)

His idiosyncrasies notwithstanding, Cheok's career had a typical beginning. As a boy he played with radio kits and programmed an Apple II; at the University of Adelaide he earned a Ph.D. in electrical and electronic engineering. He took a job at Mitsubishi Electric in 1996 because Japan was the mecca for technology, he says. In Mitsubishi's Osaka lab he spent a few years working on projects like controllers for a new high-speed train. But he chafed at the rigid company structure, and when the National University of Singapore called about a professorship, he took it.

Academia has been a good fit. In 2008 he moved back to Japan to join Keio University's Graduate School of Media Design, where he has a mandate to engage in blue-sky research and nurture the next generation of creative innovators. "Instead of having your tech guy over here and your creative guy over there, we need them to coexist in the same brain," he says.

He's still dedicated to building multisensory communication gadgets: "I believe we need to move from the age of information, which we have reached today, into the age of experience," he says. A 2007 project extended the chicken research to children: The Huggy Pajama allows faraway parents to give their kid a good-night hug by pressing an input module's buttons. In user surveys, parents and children reported higher levels of emotional engagement thanks to the huggy system. Now Cheok's working on a commercial product that would let a user send a squeeze—and a warm thought—to the ring on a loved one's finger.

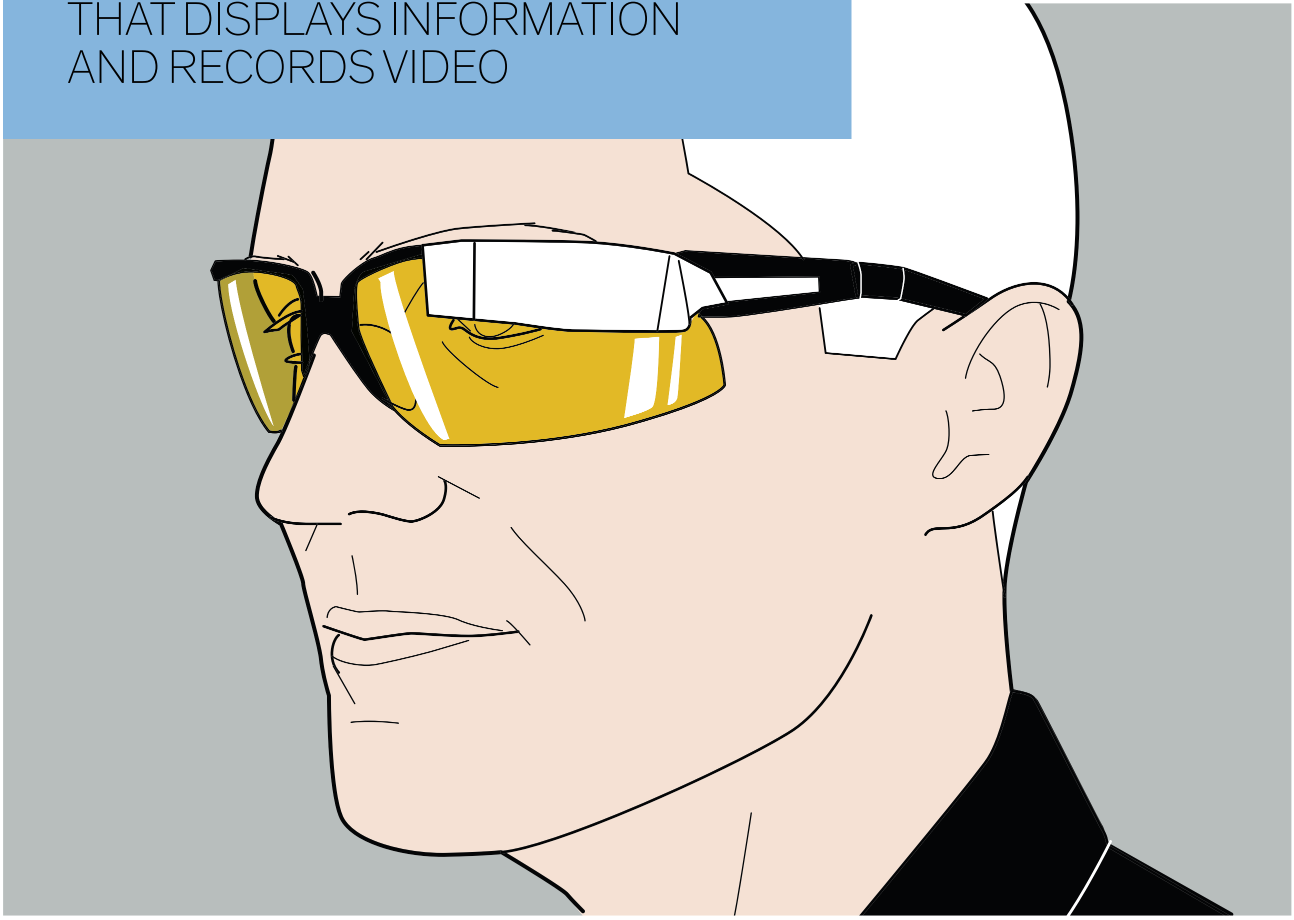
Haptics are just the beginning. Cheok has a "digital lollipop" in the works that electrically and thermally stimulates the tongue to produce basic flavors—bitter, sour, salty, sweet. He dreams of a system that would let vacationing friends in Paris send you a taste of their wine. "The ultimate Internet," he says, "will integrate all our senses." **—ELIZA STRICKLAND**

A version of this article appeared online in November.

RESOURCES_HANDS ON

BUILD YOUR OWN GOOGLE GLASS

A WEARABLE COMPUTER THAT DISPLAYS INFORMATION AND RECORDS VIDEO



LAST APRIL, Google announced Project Glass. Its goal is to build a wearable computer that records your perspective of the world and unobtrusively delivers information to you through a head-up display. With Glass, not only might I share fleeting moments with the people I love, I'd eventually be able to search my external visual memory to find my misplaced car keys. Sadly, there is no release date yet. A developer edition is planned for early this year at the disagreeable price of US $1500, for what is probably going to be an unfinished product. The final version isn't due until 2014 at the earliest [see "Google Gets in Your Face," in this issue]. ● But if Google is able to start developing such a device, it means that the components are now available and anyone should be able to follow suit. So I decided to do just that, even though I knew the final product wouldn't be as sleek as Google's and the software wouldn't be as polished. ● Most of the components required for a Glass-type system are very similar to what you can already find in a smartphone—processor, accelerometers, camera, network interfaces. The real challenge is to pack all those elements into a wearable system that can present images close to the eye. ● I needed a microdisplay with a screen between 0.3 and 0.6 inches diagonally, and with a resolution of at least 320 by 240 pixels. Most microdisplays will take either a composite or VGA video input, the former being the easiest to work with. A quick search on the Alibaba global supply website returned several candidates; most suppliers will gladly fulfill orders for a single display and matching control electronics if you contact them directly. However, the corresponding optics for mounting these displays—which required them to be placed directly in front of the eye—were too bulky.

To build a sleek device, I needed to be able to mount the actual display on the side of the head and bring the image around to the eye. This setup is actually easy to make if you have the right equipment, which I don't. Luckily, back in 2009, a company called Myvu (now

ILLUSTRATIONS BY Jason Lee

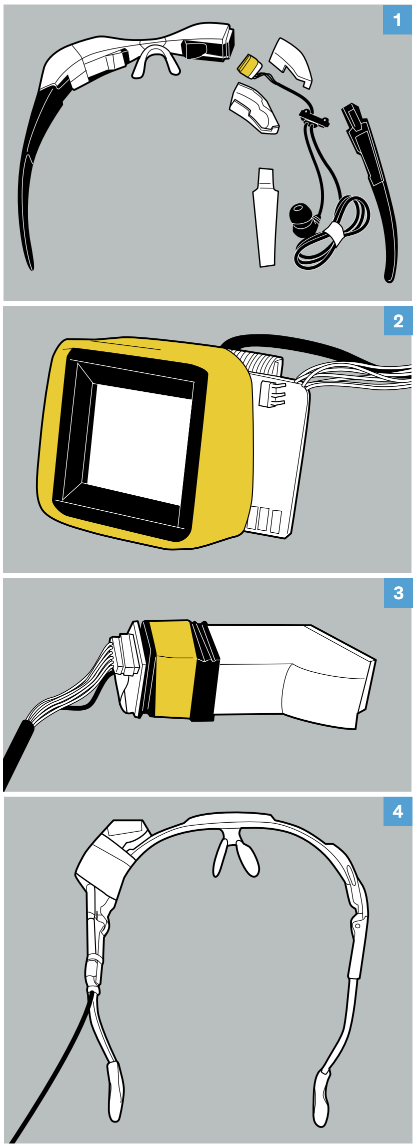
out of business) sold a line of personal head-mounted video displays for iOS devices. Myvu's products were sleek and small because they used a clever optical system alongside side-mounted screens.

I was able to procure a Myvu Crystal on eBay for just under $100. Within it I found several components needed for my wearable computer: optics, a 0.44-inch microdisplay, and a display controller capable of handling a composite video input. For the frame on which to mount the screen, I tried several kinds of safety goggles before settling on the ones that worked best.

Next, I needed an onboard computer. Since I was using a display controller that accepted only a composite video input, the obvious choice was a smartphone or programmable media player with an analog video output, such as an earlier model Apple iPhone or iPod Touch, or one of several Android phones. After considering the dimensions of all these systems, it was clear that having all the components head mounted (as with Google Glass) wasn't a viable option, so the onboard computer became a separate component that would reside in a pocket and drive the microdisplay via a cable.

I settled on a fourth-generation iPod Touch. I had to "jailbreak" it, which eliminates limitations built into the iOS software by Apple. Once that was done, I could mirror the Touch's main display to the microdisplay using its composite video output. This choice of onboard computer meant that for a point-of-view camera (used to record images and video), I needed one that could communicate via the iPod Touch's Wi-Fi or Bluetooth wireless interfaces. I used a Looxcie Bluetooth camera, which is small enough to be mounted on the side of the frame once you strip it from its plastic shell; you can order it online for around $150. (I'm already building a second iteration of my prototype around a Raspberry Pi. This will allow more control over the camera than is currently possible with the iOS apps that work with the Looxcie and better integration of sensors such as accelerometers.)

CREATIVE CANNIBALISM



The critical component for any Glass-type wearable computer is the microdisplay, which feeds information to the eye. I found a discontinued head-mounted display online and carefully disassembled it (1) to extract the microdisplay (2) and the optics (3) required to focus the image properly. I then mounted these components on a pair of plastic safety goggles (4).

My world changed the day I first wore my prototype. At first there was disappointment—my software was rudimentary, and the video cable running down to the onboard computer was a compromise I wasn't particularly pleased with. Then there was discomfort, as I felt overwhelmed while trying to hold a conversation as information from the Internet (notifications, server statuses, stock prices, and messages) was streamed to me through the microdisplay. But when the batteries drained a few hours later and I took the prototype off, I had a feeling of loss. It was as if one of my senses had been taken away from me, which was something I certainly didn't anticipate.

When I wear my prototype, I am connected to the world in a way that is quintessentially different from how I'm connected with my smartphone and computer. Our brains are eager to incorporate new streams of information into our mental model of the world. Once the initial period of adaptation is over, those augmented streams of information slowly fade into the background of our minds as conscious effort is replaced with subconscious monitoring.

The key insight I had while wearing my own version of Google Glass is that the true value of wearable point-of-view computing will not be in the initial goal of supporting augmented reality, which simply overlays information about the scene before the user. Instead, the greatest value will be in second-generation applications that provide total recall and augmented cognition. Imagine being able to call up (and share) everything you have ever seen, or read the transcripts for every conversation you ever had, alongside the names and faces of everyone you ever met. Imagine having supplemental contextual information relayed to you automatically so you could win any argument or impress your date.

Creating the software and hardware for such a "brain prosthesis" is certainly within the realm of possibility for the next decade, and I expect to see these features drive the mass adoption of the Google Glass technology. **—ROD FURLAN**

An artificial intelligence researcher and investor, Rod Furlan can be found online at BitCortex.

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OTHER PEOPLE'S KNOWLEDGE

I was visiting a high-tech company whose principal business was advanced chip design. A young engineer showed me his latest prototype. It was a circuit board dominated by a single large integrated circuit. It contained, he told me, more than 2 billion transistors. ¶ I'd never done anything remotely similar myself, and I wondered how I'd feel as a new engineer in some company being given a "Mission: Impossible" assignment like that. "How can you possibly design something so complex?" I asked. ¶ The young engineer just shrugged his shoulders. No big deal, he appeared to be saying. After a little further prodding, he confessed that, after all, there was a large collection of previously designed cells, and the computer design tools were pretty awesome. Not much to it, really. ¶ Technology has gotten exponentially more complex with the passing years, and yet engineers are turned out of universities in the same four-year cycle that they used decades ago. How is this possible?

I remember dimly that when I got out of school, I thought I knew all there was to know about electrical engineering and that, to use the term of the old trade unions, I was a "master of engineering." Of course, that wasn't right, even back then, but now there is no pretense: No one knows all of electrical engineering. Our profession has splintered into many specialties, and they, in turn, into subspecialties.

As with any deeply complex problem, the approach in engineering design is to partition the task into noninteracting subsystems and attack each independently. Thus our world has become compartmentalized and layered, with well-defined interfaces between the layers. It is as if each had a warning label that said, "No user-serviceable parts inside."

The young engineer working on chip design depends on the work of other people, in the adjoining layers, who have already designed the cells he uses and who worried about the electrical characteristics at the base circuit level. Still others will, in turn, take his chip for granted and write software to produce functionality, implementing algorithms derived by theoreticians, while still others will worry about the user interface.

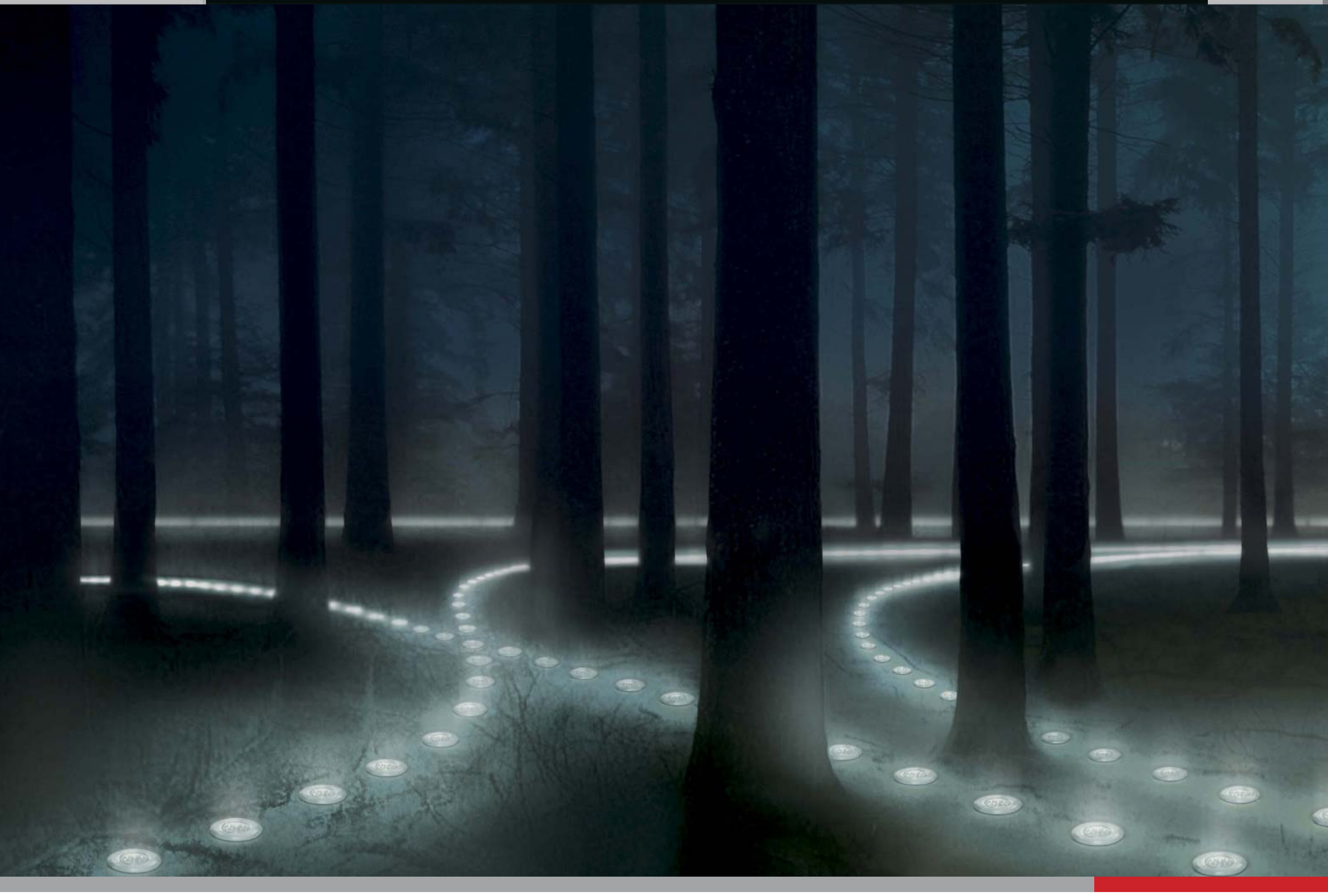
The young engineer will work shoulder to shoulder with a computer whose software tools codify design rules that have been learned through the years of experience by many other engineers–intricacies none of them know except collectively. Where necessary the software tools will do the math for him–math he may have forgotten or never learned. In every direction around him, he will rely on other people's knowledge. The bad news is that this engineer will never know all of engineering; the good news is that he doesn't have to. The world doesn't work that way anymore.

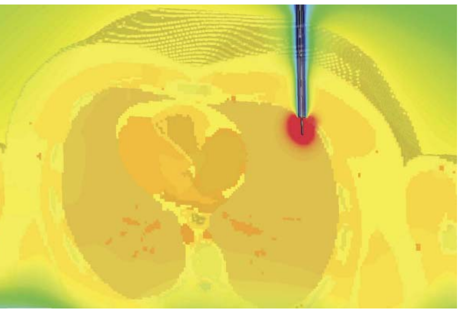
What is wonderful today is how easy it is to tap into other people's knowledge. In the olden days–that is, before the Internet–we had to find the right person to ask for help, or we had to wade through libraries for stale, encrusted information. Now we start by asking the world at large: "How do I do or fix this?" Chances are, we're not the first to ask, and some stranger has already provided the answer. We can get continuously updated tutorials from Wikipedia, and there is an ever-growing collection of online lectures on technical subjects. There may even be a YouTube video titled "How to Design a 2-Billion-Transistor Circuit."

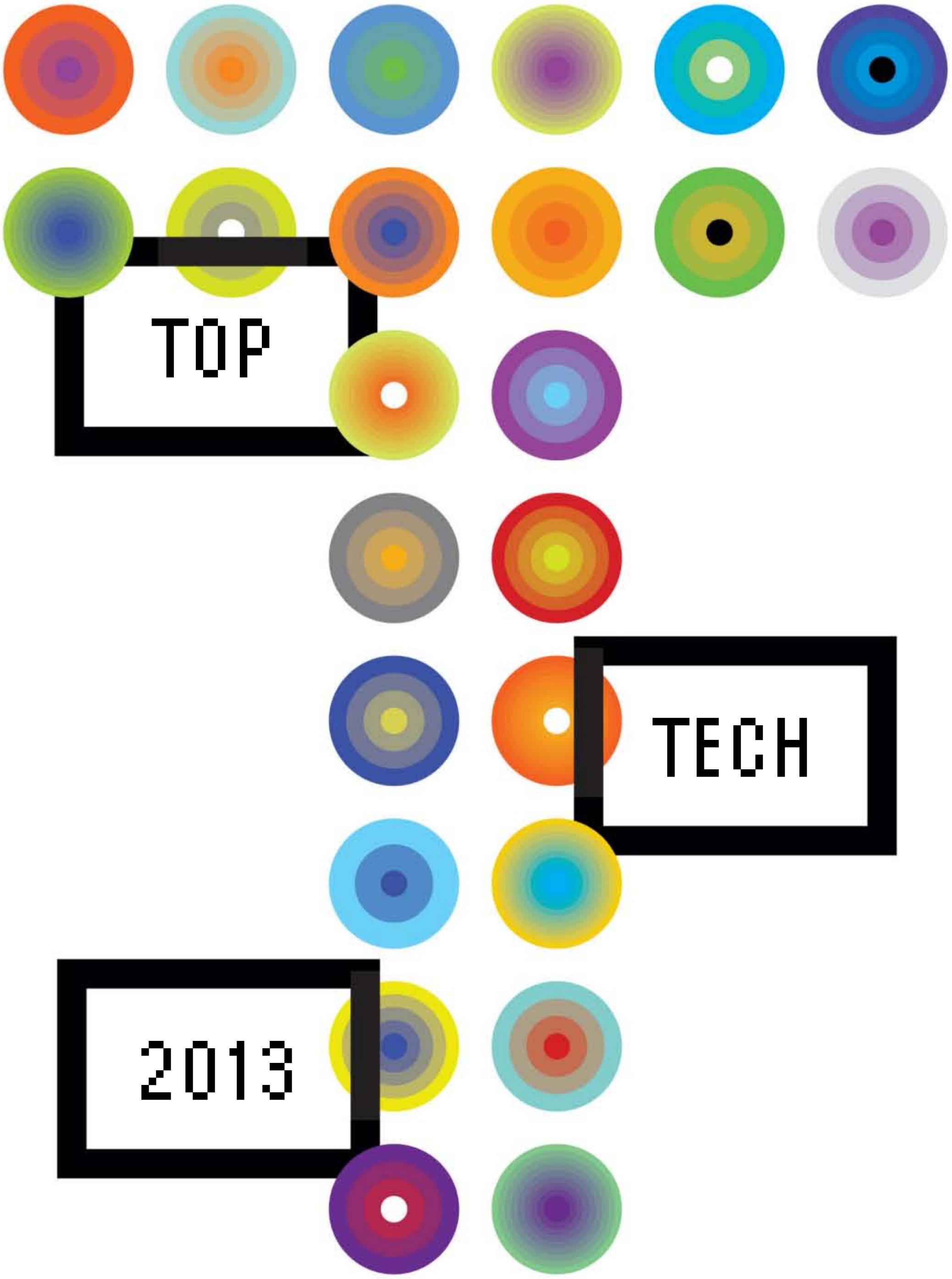
In such a world, what does the engineer need to know? First, how to skillfully acquire information–but today, everyone is fairly good at that. Next, he or she should know something about all the layers, a good deal about his or her own layer, and even more about some niche within it. But most engineers are good at turning the crank once a problem is defined; the talent that characterizes the best engineers is realizing what problems need to be solved.

After a few years out of school, much of the knowledge an engineer applies will have been learned on the job, through continuous education and just-in-time knowledge acquisition. His or her university education will have provided the fundamentals and core principles of engineering–whatever they are. I'm not so sure anymore. ■

ILLUSTRATION BY Jesse Lefkowitz







IT'S IMPOSSIBLE TO PREDICT NEXT WEEK'S WEATHER, but all too easy to predict next year's: In January 2014, it will be cold in Helsinki and hot in Rio. In any field, it's the midterm prediction that hits the sweet spot–it's neither too hard to be done nor too easy to be interesting. That's why we've focused our annual technology survey on the coming 12 months. ▶ Google Glass will bring the Internet to your eyeballs, but what will you do with it? An enormous canal in China will water that country's parched north, but at what cost? Intel will mount a serious attack on the mobile market, but how will it do that? Of course, not all our prognostications were difficult: We absolutely guarantee that the infinitesimal vestiges of serenity remaining in airline cabins will be demolished as they are pervaded by cellphone chatter. ▶

Carl DeTorres

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2013 TECH TO WATCH

GOOGLE GETS IN YOUR FACE

GOOGLE GLASS OFFERS A SLIGHTLY AUGMENTED VERSION OF REALITY

BY ELISE ACKERMAN

ILLUSTRATION BY EDDIE GUY

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FOR THE PAST NINE MONTHS, GOOGLE HAS BEEN PRIMING THE PUBLIC FOR THE LAUNCH OF GOOGLE GLASS, A HEAD-MOUNTED, INTERNET-ENABLED DISPLAY THAT—IF YOU BUY THE HYPE—WILL REVOLUTIONIZE COMPUTING AND TOTALLY ROCK YOUR WORLD.

AM I SMART YET? According to Google, Glass will let you access information "so fast that you feel you know it."

GOOGLE

A marketing blitz featured skydivers sporting Glass as they plummeted to Earth and runway models doing their best to strike a modish pose with the smart glasses perched on their noses. A YouTube video promoting the new specs tailed a man as he woke up, ate breakfast, went to a bookstore, met a friend, and shared a sunset with his girlfriend, all while receiving a stream of messages and augmented information about his surroundings on his Google Glass display.

In the next few weeks, Google will start shipping its smart spectacles to developers. More-polished consumer models are expected in 2014.

Is it worth the wait? Truth is, today's Glass is more like a head-mounted smartphone than a true augmented reality appliance like the one featured in the YouTube video. It can't superimpose tags, grids, maps, or running commentary on whatever you happen to be looking at. And despite the company's attempt to associate Glass with high fashion, it still cries out *nerdware*. "Google–most of us use it every day," observed comedian Jon Stewart. "But have you ever thought, 'The real problem with Google is it's too far from my face'?"

Details about Glass are still sketchy. The lightweight browband, which looks like an ordinary pair of reading glasses minus the lenses, connects to an earpiece that has much the same electronics you'd find in an Android phone: a microprocessor, a memory chip, a battery, a speaker, two microphones, a video camera, a Wi-Fi antenna, Bluetooth, an accelerometer, a gyroscope, and a compass. The microdisplay is positioned over one eye.

That hardware lets Glass record its wearer's conversations and surroundings and store those recordings in the cloud; respond to voice commands, finger taps, and swipes on an earpiece that doubles as a touch pad; and automatically take pictures every 10 seconds. Prototypes connect to the Internet through Wi-Fi or through Bluetooth and a smartphone. Future versions will likely include a cellular antenna.

The company says Glass will be small enough, light enough, and stylish enough to wear all day, like a favorite fleece or a comfy pair of sneakers. Glass will run apps like Google+ and Google Search, but it's designed to feel more natural and immersive than a PC or a smartphone. Ideally, Babak Parviz, the leader of Project Glass, told developers at the company's Google I/O conference in June, it will let you access information "so fast that you feel you know it." [A Q&A with Parviz is at http://spectrum.ieee.org/parvizinterview.]

That's right: Google says that Glass will make you feel smarter. "We're talking about a device that sees everything you see and hears everything you hear," says Rod Furlan, an artificial intelligence researcher and angel investor. "From the starting line what you are gaining is total recall."

TO BECOME MORE than a niche product, though, Glass must clear a few hurdles.

First, there's the competition. "If Google Glass gets commercial traction, everybody and their brother will start building similar displays and interfaces," predicts Alex "Sandy" Pentland, director of MIT's Human Dynamics Laboratory.

That's already happening. Start-ups Atheer, First Person Vision, Lumus, and Vergence Labs all have Glass-like prototypes in the works. Specialty manufacturer Recon Instruments makes MOD Live, a head-up display for skiers that analyzes their jumps. Established firms like Apple, Microsoft, Olympus, and Sony have been conducting research into smart glasses and head-up displays for years.

ILLUSTRATION BY L-Dopa

All that activity may finally add up to a robust market for smart glasses, says Theo Ahadome, a senior analyst at British market research firm IMS. If Google Glass is embraced by early adopters, Ahadome thinks the market could grow from less than US $1 million today to $700 million by 2016. If the products then spread to mainstream consumers, that figure could jump to several billion, he says.

Already, Glass seems to have thrown a lifeline to an industry that has struggled for decades. In May, shortly before Glass was unveiled, Vuzix Corp., a 20-year-old company that makes augmented-reality eyewear, stated in a filing with the U.S. Securities and Exchange Commission that "doubt exists about our ability to continue as a going concern."

Since Google's announcement, however, Vuzix has renegotiated loan agreements, signed a development contract with the U.S. Army, and announced a Glass-like version of its eyewear to be released in early 2013. Built on the Android 4.0 operating system, Vuzix Smart Glasses M100 won a Best of Innovations award at this year's International Computer Electronics Show, in Las Vegas. "Google is getting people to think about all the new experiences they can have using see-through displays and sensors," says Paul Travers, CEO and founder of Vuzix.

But even Google will have to convince people that wearing a computer on their faces all day is something they want to do, a hard sell even to technophiles. "I'm not hugely interested in Google Glass because, although I'm very keen on augmented reality, that's not what Google Glasses are," science-fiction writer Bruce Sterling wrote in an e-mail to *IEEE Spectrum*. "Google Glasses are more like a head-mounted Android unit, and there's not much in the way of live interaction with 3-D virtual images."

Steve Mann, a professor at the University of Toronto who pioneered the development of Glass-like devices in the 1980s, says Google appears to be making some of the same design mistakes he made with his early prototypes. Specifically, he says, positioning a microdisplay outside a person's natural field of view could lead to eyestrain and visual confusion. "It doesn't make you smarter. It makes you dizzier and more confused," he says, adding that the display should be directly in front of the eye, like a product he developed called EyeTap. [For the complete interview with Mann, go to http://spectrum.ieee.org/manninterview0113.]

Even if Mann's worries prove unfounded, Glass's battery life and processing heft will be a big issue; any application involving computer vision and streaming video will likely be a power and computing hog. Right now, the batteries reportedly last just 6 hours. Some developers are also grumbling about the $1500 price tag for the early prototypes. Presumably, the consumer version will be cheaper.

LET'S ASSUME, though, that Google does win over millions of people. What then? Privacy advocates warn that Glass, and similar devices, could lead to an unprecedented loss of control over your personal information.

"The question is, what will Google do with the information they are collecting?" says Rebecca Jeschke, a spokeswoman for the Electronic Frontier Foundation, a leading privacy rights group. The company hasn't revealed any Glass-related privacy policy, but the fact that the data exists in the cloud puts it within the reach of third parties. Current U.S. statutes allow law enforcement access to e-mail and cellphone records under certain circumstances without a search warrant. Governments in Australia, Canada, and the United Kingdom are seeking to expand their electronic monitoring powers.

MIT's Pentland counters that the risk to privacy can be reduced if companies like Google provide people with full control of their own data. Making sure people know when they are being recorded will also help. And, he adds, governments are already pressuring corporations to adopt more privacy-friendly practices. The Consumer Privacy Bill of Rights, announced by the White House last February, and a joint declaration on protecting personal data signed last March by the United States and the European Union are evidence that the world is moving in the right direction, he says.

Others view the hand-wringing over privacy as passé. "We will soon be living in a hypervisible society, and there is nothing we can do to stop it," argues Furlan, the artificial intelligence researcher. "It's not about fighting the future; it's about learning to live with it."

Furlan was so eager to see what a future with Glass might look like that last summer he built his own prototype from off-the-shelf parts [see "Build Your Own Google Glass," in this issue, to learn how he did it]. It streams e-mail, Twitter updates, text messages, and the status of his servers to a monocular microdisplay. At first, he says, the flood of information felt overwhelming, but now when he takes off the gadget, he feels "impoverished."

He can't wait to try the real Glass. Furlan believes Google's expertise in data and in machine learning will lead to all kinds of applications that enhance people's everyday experience. Yes, he says, you'll have to give up some privacy, but the trade-off will be worth it. "In the end, I believe technology gives more than it takes," Furlan says. ■

WILL MICE STILL SUFFICE?

Or will we prefer Leap Motion's hand-wavy device?

In the sci-fi thriller *Minority Report*, Tom Cruise showed off a glitzy gesture-based user interface, part of the 2054 future the movie depicted. Get ready for such interfaces to arrive en masse in 2013.

The biggest promises come from San Francisco–based Leap Motion, which will soon be offering a US $70 add-on the company claims can track movements of your hands and anything they're holding with a resolution of just 10 micrometers. Leap Motion hasn't described the technology. But if its über-Kinect performs anywhere near as well as claimed at such a low price, expect it to rival the mouse as a way of manipulating computers. —DAVID SCHNEIDER

CARBON CAR

BMW WILL INTRODUCE THE FIRST AFFORDABLE CARS MADE WITH SUPERLIGHT CARBON COMPOSITES

By Lawrence Ulrich

RUMPELSTILTSKIN FAMOUSLY spun straw into gold, and until recently, the idea of weaving superlight carbon fiber into mainstream cars also seemed a fairy tale.

The reason? Carbon-fiber-reinforced plastic, or CFRP, is expensive. Back in 1992 the cost was insanely high–U.K.-based McLaren Automotive needed 3000 man-hours to hand-layer, mold, and cure the material into the bones of the US $1 million F1, the world's first street-legal carbon car. And even though McLaren now builds the 75-kilogram carbon chassis of its MP4-12C supercar in just 4 hours and sells the car for $225 000, that's still too steep for the average buyer.

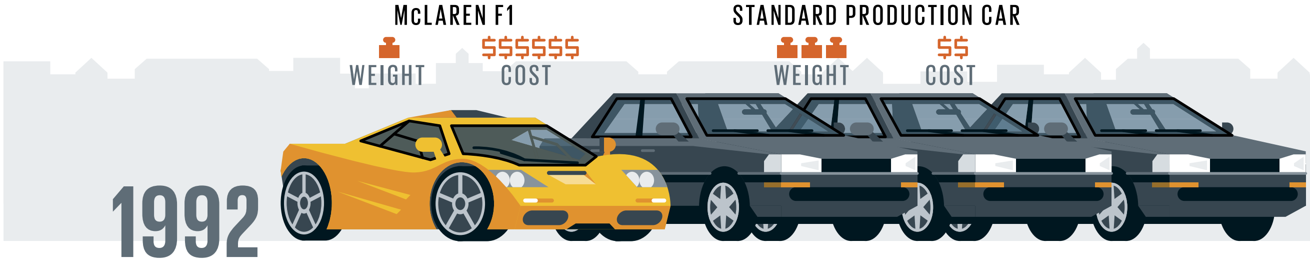
But now BMW is unveiling a technology that it says can mold a woven sheet of carbon fiber into a completed car part in less than 10 minutes. Those parts will go into the groundbreaking BMW i3, a plug-in hybrid that analysts estimate will cost just $40 000 to $50 000 per car, barely more than the price of a Nissan Leaf EV.

The i3 is a funky, tall-roofed city car with a roughly 160-kilometer range, a 160-km/h top speed, and a carbon-fiber "Life" module that weighs just 120 kg–less than some passengers. The car is set to emerge from a plant in Leipzig, Germany, in late 2013, and production is expected to ramp up to as many as 40 000 units a year.

In 2014 the company will start making the i8 hybrid, a futuristic sports car that starred in *Mission Impossible: Ghost Protocol* (2011). In both BMWs, the CFRP passenger module mates to a separate module that integrates the power train, lithium-ion battery, suspension, and aluminum crumple zones.

Building moderately priced cars from CFRP had long been a holy grail for automotive engineers, because a carbon chassis weighs half as much as a steel counterpart and 30 percent less than aluminum. The savings in weight translates into better performance and higher fuel efficiency. Therefore, it's a material of choice for everything from Formula One racers and America's Cup yachts to jet fighters, spacecraft, and the Boeing 787.

BMW



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Cost was the sticking point. "Time and again, everyone said it was impossible," says Joerg Pohlman, director of BMW's carbon fiber projects. The technology took hundreds of millions of dollars of research and development to perfect.

The company now intends to begin building more than 1 million carbon-fiber components a year and to eventually base many of its cars on the material.

A linchpin of the plan is in Moses Lake, Wash., where the lure of cheap, clean hydropower sparked a $100 million partnership between BMW and Germany's SGL, among the world's top manufacturers of carbon-based products. BMW and SGL bill it as the world's greenest, most efficient carbon-fiber plant. That's one reason why the i3's total life-cycle carbon dioxide emissions will be one-third less than that of the most efficient internal-combustion cars—50 percent less if the i3 is recharged using renewable energy.

Along Moses Lake's 245-meter production line, bundles of 50 000 silky white polymer acrylic strands—each a tenth as thick as a human hair—are carbonized in furnaces at 1400 °C. Spools of the black fiber head to Wackersdorf, Germany, where they're woven into sheets. At another German factory, sheets are pressurized, impregnated with liquid thermosetting plastic, and molded—in BMW's speedier, proprietary take on resin-transfer molding—to form finished components in less than 10 minutes. The trail ends in Leipzig, where components are glue-welded together, forming the bones of a radically new type of car.

Pohlman says other efficiencies will make carbon fiber about as inexpensive to manufacture as aluminum within three to five years. Instead of 350 or 400 metal parts, the i3's chassis has about 35. The simple construction—a bit like gluing together a model car—eliminates dozens of factory welding robots and manufacturing stations. And unlike steel—even clear-coated steel—carbon fiber never rusts, requires no costly corrosion treatments, and is designed to last for decades with minimal structural fatigue. The plastic underpinnings, experts say, will long outlast the cars and technology that surround them. True, that raises the question of how to recycle the stuff, which is tricky, because recycled fiber isn't strong enough to reuse in a car chassis.

As ever, government fuel-economy regulations are largely driving this structural revolution, making "lightweighting" one of the biggest automotive trends around the world.

In the United States, President Obama has called for manufacturers of cars and trucks to double their fuel economy by 2025, to a lofty 54.5 miles per gallon (4.3 liters per 100 kilometers). The European Union targets a 40 percent reduction in automotive CO_2 emissions by 2018; the target of 130 grams of CO_2 per kilometer driven equates to 5.6 L/100 km, or 42 mpg.

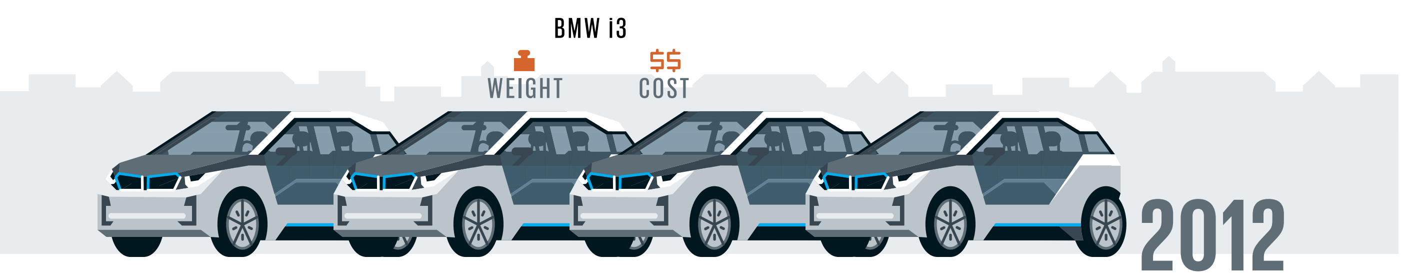
The problem is that cars have been porking out for decades, adding power along with air bags and other crash protection. Then there's such froufrou as 20-inch wheels, navigation systems, and seats that heat, cool, and massage their spoiled occupants.

Both regulators and customers "demand more safety, features, and comfort, but at the same time we are forced to [make them] lightweight," Pohlman says. "And the response can't be to take out seat belts and the nav system." ■

AUTO GIANTS BET BIG ON MINI EVs

GM and Toyota enter the market for battery-powered urban vehicles

Should nuclear-tinged tensions with Iran and resurgent economic growth in China blow gasoline prices sky-high again, the top two automakers will be ready with pint-size electric city cars. They thus follow the lead of Renault's Twizy, starting at €6990 (US $9000), an open-cab two-seater that was vying for the top spot in European electric-car sales last year. General Motors is promising to test its EN-V 2.0 prototype runabout throughout China, while Toyota will offer Japanese urbanites a two-rider version of its Coms electric minicar this year. Japan recently deemed ultracompacts to be street legal—a prerequisite to bringing these tiny electrics to North America. —PETER FAIRLEY



ILLUSTRATIONS BY L-Dopa

2013 TECH TO WATCH

THE GREAT CANAL OF CHINA

BRINGING WATER TO THE THIRSTY NORTH

By Eliza Strickland

CHINA'S ENGINEERING MOTTO could be summed up as "Go big or go home." In the past decade the country has built the largest hydroelectric dam and the most expansive high-speed rail network in the world. Now it's working on the planet's largest water transfer project, the first route of which is scheduled to begin operations in 2013.

The South-to-North Water Diversion Project will realize an old dream of Mao Zedong: to bring water from monsoon-swept lands, where it's plentiful, to the north's booming industrial cities, where it's not. The eastern route, which will be put into service this year, takes water from the Yangtze River and carries it up the seaboard provinces. The 1467-kilometer-long canal will be the longest in the world; it will initially be capable of pumping 8.8 million megaliters of water annually, enough to fill 28 000 supertankers. Future expansions will eventually increase its capacity to 14.8 million ML per year.

Much of the eastern route builds on the Beijing-Hangzhou Grand Canal, some parts of which date back to the 5th century BCE. The ancient canal held mostly stagnant water, which was good enough to float barges filled with grain to the north. When the new eastern route opens for business, it will use 34 pumping stations, sucking 366 megawatts, to transport water instead. The pumps will propel the water half the way, up gradually rising terrain; then the canal tunnels under the Yellow River, after which gravity carries it the rest of the way.

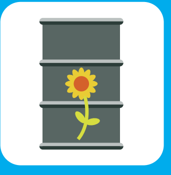
According to China's Ministry of Water Resources, the total cost for the eastern route is expected to top US $8.5 billion, which includes nearly $2.5 billion for water treatment facilities. That's necessary because the canal travels through a number of industrial zones and densely populated areas, and water pollution is a serious problem. Other possible consequences of the eastern route are water shortages in the south, damage to the Yangtze watershed, and high water prices in the north (as a result of the project's massive expenses). Yet the ministry hasn't released anything resembling a cost-benefit analysis, and the agency is pushing ahead with the project's next phase.

The project's central route, which will bring water to Beijing and Tianjin, may be completed in 2014. That canal may cost another $37 billion, according to the ministry, and it requires the expansion of a reservoir and the resettlement of about 345 000 people. A third and final route in the west would transport water from the Tibetan plateau, but the Chinese government has reportedly postponed that technically challenging and politically controversial route. ■

ILLUSTRATION & MAP BY L-Dopa

GREENING CANADA'S TAR SANDS

An Alberta start-up says it has a cleaner way to extract oil



By this May, a US $60 million field test should be pumping bitumen out of Alberta's tar sands while using virtually no water and 85 percent less natural gas per barrel than today's methods. Rather than injecting steam to melt buried bitumen so it can be sucked hundreds of meters up to the surface—the energy-intensive process used to extract close to 1 million barrels per day of Canadian bitumen—Calgary-based N-Solv Corp. will dissolve the sticky stuff with recyclable butane and similar chemicals. Success would shrink bitumen's carbon footprint and blunt the opposition to expanded exploitation of this fossilized fuel. However, it might slow the shift to petroleum-free transport alternatives, such as electric vehicles. —PETER FAIRLEY

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TO INFINITY AND BEYOND: TICKETS, PLEASE!

2013 SHOULD SEE THE FIRST COMMERCIAL PASSENGER FLIGHTS TO THE EDGE OF SPACE

By David Schneider

ILLUSTRATION BY EDDIE GUY

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IN THE HIGH DESERTS OF NEW MEXICO, NOT FAR FROM THE BISON GRAZING ON TED TURNER'S SPRAWLING ARMENDARIS RANCH, LIE SOME CURIOUSLY OTHERWORLDLY STRUCTURES. THE LARGEST ONE PRESENTS A 15-METER-HIGH WALL OF GLASS

HEADING HOME: SpaceShipTwo soars over California's Mojave Desert during its first gliding test flight, in 2010.

VIRGIN GALACTIC

on one flank, although the rest of the building appears to have buried itself in the adjacent earth, as if it had crash-landed there. Just a couple of hundred meters away sits a low-slung dome with something that resembles a giant eye budding from the top. "It almost looks like a spaceship itself," quips David Wilson, who handles media relations for the site.

The squat dome will house the operations center for this futuristic facility, called Spaceport America, the first spaceport ever built expressly for commercial use. And by the end of the year, Spaceport America should be home to the first-ever "spaceline": Virgin Galactic, part of Sir Richard Branson's London-based Virgin Group.

Once Virgin Galactic's routine flights begin, ordinary people—at least, ordinary people with US $200 000 to spare—will be able to buy tickets into space. True, the company won't take them into orbit, but it will fly them 100 kilometers (62 miles) above sea level to the Kármán line, which the Fédération Aéronautique Internationale defines as the edge of space.

To get there, they'll have to have at least a dollop of the right stuff. The six passengers and two pilots will take off horizontally from the spaceport's 3.7-kilometer-long runway in a space plane that will likely have the ambiance of a trendy business jet. This craft—dubbed SpaceShipTwo by the company that designed it, Mojave, Calif.-based Scaled Composites—will be slung beneath a double-fuselage carrier aircraft, WhiteKnightTwo, on takeoff and for the flight's first couple of hours.

The real adventure begins after the two linked craft rise about 15 km (50 000 feet), at which point SpaceShipTwo will drop from its mounting, fire up its rocket motor, and go zooming upward into the heavens. Its passengers will then experience peak forces that are almost 4 *g*'s—four times normal gravity—more than what a ride up on the space shuttle gave its astronauts, although for passengers on SpaceShipTwo the push into their seats will last for just a minute or so. The feeling of acceleration will abruptly disappear when SpaceShipTwo's rocket motor shuts down, as the craft coasts upward through a broad arc that will give its occupants about four minutes of free fall, or "weightlessness."

Although Virgin's plans do not include having flight attendants on board, the company is promising passengers that at this point of their flight they will be free to move about the cabin, as they say. (The pilots will no doubt joke with them about the dangers of unexpected turbulence.) After floating over to press their noses to the windows and spending some time enjoying a magnificent view of star-dappled blackness behind Earth's curved horizon, these new astronauts will have to reseat themselves for the leg back home.

The wings of SpaceShipTwo are hinged, just like those of its predecessor, SpaceShipOne, which won the $10 million Ansari X Prize in 2004 by overtopping the Kármán line twice within a span of two weeks. Burt Rutan, founder of Scaled Composites and the designer of SpaceShipOne, realized that by rotating the aft section of its wings by about 65 degrees, the craft would be aerodynamically stable as it fell back into the atmosphere. Scaled Composites describes the resultant reentry as "hands-off" or "care-free." But passengers probably won't feel so carefree when they begin to experience the deceleration–up to 6 *g*'s worth at peak (although that level lasts only for seconds).

Can ordinary folks really handle such rigors without incident?

"Going to 6 *g*'s is a serious thing, but it's a very trainable thing," says George T. Whitesides, president and chief executive officer for Virgin Galactic. "We put 80 of our earliest customers through that exact *g* profile and the vast majority did fine." Lynda Turley Garrett, a travel agent based in Saratoga, Calif., and an "accredited space agent" for Virgin Galactic, traveled to the National AeroSpace Training and Research Center in Southampton, Penn., where she rode a simulator-equipped centrifuge that duplicated the forces that Virgin's passengers will be challenged by. Not only did she not black out, she found the experience thrilling. "It was 100 times better than any roller coaster I've ever been on," she says.

More than 500 people have already signed up to get a taste of space with Virgin Galactic. Those who want to reserve the next available seat (as most have done) must pony up the full fare, so it's no casual commitment. Whitesides expects that it'll take his company more than a year from when commercial operations begin to find seats for all those who have put money down so far. And exactly when passengers will begin flying is unclear. But Branson has said that the first such flight, on which he and his two grown children will be passengers, should occur sometime this year.

It's understandable that the timetable is still a bit vague. Ferrying ordinary people to the edge of space is, after all, not something anyone really knows how to do yet. While the U.S. Federal Aviation Administration is working hard to ensure all goes without incident, its role here is much more restricted than it is with airline travel. "The FAA is not certifying that the vehicle is safe," says Whitesides, explaining that's because there are no established procedures for safety certification when it comes to commercial space vehicles. "We'll be operating in a somewhat unique regulatory regime based on informed consent," says Whitesides. "The operator informs the customer [about the risks], and the customer makes the decision."

How you judge the risks, though, isn't so clear. The big question mark is SpaceShipTwo's rocket motor. As with SpaceShipOne, that motor will be of hybrid type, using a solid fuel (a rubber-like polymer) and a gaseous oxidizer (nitrous oxide). "People have long recognized that hybrids have an inherent safety advantage," says Brian Cantwell, a professor of aeronautics and astronautics at Stanford. That's because even with a catastrophic failure of the motor, the fuel and oxidizer can't mix easily. Hybrids have, however, been slow to catch on in the rocket business, because most of these designs provide underwhelming oomph. "The hybrid was perfect for SpaceShipOne because it did not require high performance," says Cantwell.

Despite the inherent safety of hybrid rockets, things can–and have–gone badly wrong with them in the past. In 2007, the oxidizer tank being developed for SpaceShipTwo's hybrid rocket motor exploded during a test of the motor's oxidizer feed system, killing three and seriously injuring three others at Scaled Composites. Such an explosion was completely unexpected, given that nitrous oxide is normally considered quite stable–the very same substance ("laughing gas") is used in countless dental offices. That a tank of this seemingly safe gas nevertheless exploded with great violence shows that hybrid rockets are not necessarily benign when they fail. "That's probably the biggest safety concern," says Cantwell. So it's no wonder that Scaled Composites and Virgin Galactic have been proceeding most cautiously toward their goal since the fatal explosion five and a half years ago.

The pace of advance for Virgin Galactic is slower than it had been for SpaceShipOne, which took only three years to go from the start of full development to winning the Ansari X Prize. But that's understandable, given the safety concerns that come with transporting passengers and the scale of things that need to be put in place to support a real spaceline. The Spaceship Company, a corporate entity created by Virgin Galactic and Scaled Composites in 2005 expressly to build these craft, is now working on a second SpaceShipTwo aircraft along with a second carrier. The plan is to build five spaceships and two carriers, which will be based at Spaceport America, meaning that operations must both scale up in size and move from California to New Mexico.

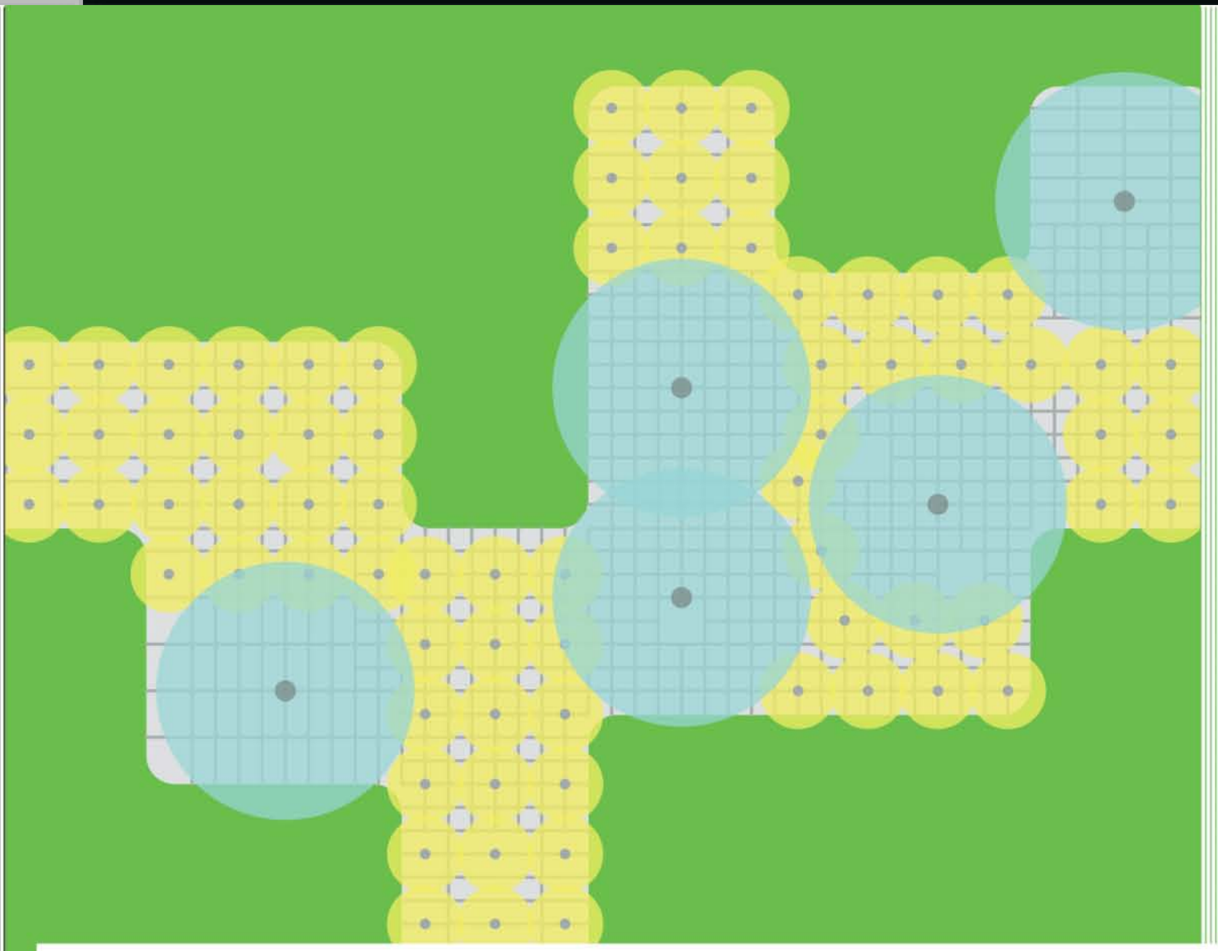
The end result should be something science-fiction writers have long dreamed of: regularly scheduled passenger flights into space. "We're going to be shooting for once a week at the start," says Whitesides. The technology is almost here to allow that, and space enthusiasts will no doubt celebrate the start of a new era when it comes, although few of them will have the means to celebrate it with a joyride into the beyond. And whether there will be a sustained demand for these \$200 000 seats is anyone's guess. ■

THE TOUGHEST LANDING

Unmanned planes will touch down on aircraft carriers

A pilot faces no greater challenge than landing on a moving aircraft carrier. The second-hardest may be taking off from one. This year, both operations—and everything in between—will be done by the X-47B, a pilotless plane built by Northrop Grumman for the U.S. Navy. The plane blends GPS navigation with optical and other sensors to pinpoint its position and avoid collisions; it comes under human control only when taxiing on the carrier's deck. The goal is for it to get in line, take off, land, and get off the deck in no more time than manned planes require. In 2014, the X-47B will take on aerial refueling—all by itself. —PHILIP E. ROSS

ILLUSTRATION BY L-Dopa



A SURGE IN SMALL CELLS

MINI CELLULAR BASE STATIONS WILL BLANKET URBAN HOT ZONES AND RURAL DEAD ZONES

By Ariel Bleicher

DURING THE MANY years he worked for Hewlett-Packard's branch in the United Kingdom, Alan Breadmore often drove up the hill outside his village of East Garston to make calls on his company cellphone. "It was the only place I could get reception," he says. "We had no mobile phone service in the village—no 2G, nothing."

With little more than 500 residents, the village had been overlooked by cellular carriers. But in early 2011, Breadmore, who now oversees infrastructure development for the village council, heard that the Vodafone Group—just 15 kilometers away in the town of Newbury—was looking to test a new cellular system. So he lobbied the company for a trial. By May 2012, engineers had installed a dozen hatbox-size appliances on utility poles, barn walls, the roofs of the village hall and pub, and even one in a decommissioned phone booth.

These miniature base stations, known as small cells, are smarter, cheaper, less obtrusive, and easier to install than traditional towers. Many carriers are now using them not just to bring service to remote locations but also to expand data capacity in congested urban centers. "It's impossible to find an operator today who doesn't believe in small cells," says Simon Saunders, who was chairman of the international Small Cell Forum until this past October.

In 2013, operators will begin deploying them in unprecedented numbers. According to Nick Marshall of ABI Research, in Oyster Bay, N.Y., global shipments of outdoor small cells—many destined for lampposts and bus stops in busy city squares—will surpass 2 million by 2016. Factor in indoor small cells—for homes, businesses, malls, and sports stadiums—and that number approaches 37 million. Informa, a European research firm, predicts that the same year, 90 percent of all cellular base stations will be small cells.

THE EARLIEST PIONEERS of small cells were chipmakers. In the mid-2000s, carriers could buy low-power cellular

ILLUSTRATIONS BY L-Dopa

base stations, called "micro" and "pico" cells to distinguish them from their high-power "macro" cousins. But these towers, whose smaller footprint made them more practical for dense urban deployments, still required thousands of transmitters, receivers, amplifiers, and filters arranged on multiple printed circuit boards. The final product was robust, but it was also bulky and expensive.

Small wireless-chip companies saw an opportunity. They recognized they could use system-on-a-chip techniques to drastically reduce cost and size. "We collapsed the entire base station onto one or two chips," says Doug Pulley, cofounder and chief technology officer of Picochip (now owned by Mindspeed Technologies), which in 2005 became the first company to demonstrate the technology. Rupert Baines, who was Picochip's marketing vice president, took to calling the tiny stations "femtocells." "Some say I invented the word," he says.

The name stuck. Big equipment makers–Alcatel-Lucent, Cisco, Huawei, Qualcomm–began buying femtocell start-ups or engineering their own products. Carriers started adopting femtocells in 2007, but only to help alleviate poor indoor coverage, not to expand public networks.

"If you looked at the traditional network architecture in place four, five years ago, frankly, it didn't support a small-cell layer," says Gordon Mansfield, AT&T's executive director for small-cell solutions and the newly appointed chairman of the Small Cell Forum. In many 3G networks, base stations are managed at centralized junctures by radio network controllers, which at the time did the lion's share of data and call processing. Signals arriving at the controllers had to travel through dedicated lines to ensure low latency and minimal packet loss. Connecting hundreds of thousands of small cells would be laborious. "We couldn't afford it," Mansfield says.

Soon, however, femtocell engineers developed standards that enabled 3G base stations to take over many key processing tasks. (Newer 4G LTE systems already have such capabilities built in.) Communication with radio network controllers could now be a little more lax, allowing small cells to "backhaul" data through shared Internet lines or line-of-sight wireless links. Small cells suddenly looked very economical. Carriers quickly realized that the technology could solve their greatest challenge: exploding demand for mobile data.

GLOBAL MOBILE TRAFFIC is more than doubling each year, according to Cisco Systems. Some wireless equipment makers, such as Nokia Siemens Networks, warn that the mobile industry will need to prepare for 1000 times as much traffic by 2020.

Operators are already feeling the strain. "Cellular networks around the world are full to bursting and are creaking at the seams," says Baines, now at Mindspeed. To deliver the data consumers want, engineers must vastly expand network capacity. The job mainly entails packing more cell sites into a given area, thereby enabling mobile appliances to reuse the available spectrum.

Engineers have typically done this by replacing the area covered by a single tower with several smaller ones, each transmitting with less power. Now they're turning to small cells, which have acquired diverse names for their many sizes and roles, including femtocells, picocells, microcells, and metrocells (not to be confused with old-school micro and pico towers).

Rather than taking the place of towers, small cells are being overlaid on the macro network as needed. Equipped with smart software, they can sense their neighbors and even expand and contract their power radii to meet changing capacity needs. In time, our orderly, honeycombed cellular grids will be dotted with dynamic cellular bubbles, creating heterogeneous networks, or "HetNets."

Engineers are still working out ways for small cells to integrate seamlessly with macro base stations and with one another. Interference is a major concern. One approach is to program overlapping base stations to intelligently share frequencies in the same spectrum. Alternately, some regulators have proposed dedicating separate high-frequency bands for small-cell use. Though traditionally considered unsuitable for cellular networks due to their short range, these frequencies could be ideal for small, low-power cells.

In just a few years, small cells may be as compact as Wi-Fi routers, says Iyad Tarazi, vice president of network development at Sprint. Consumers may even be able to buy one for the price of a smartphone. "Anywhere you go, you could take that coverage and capacity with you." ■

TALKING DOWN TO PEOPLE

In-flight mobile phone service takes off

Soon you'll finally get to use your phone while flying—and also listen to your neighbors yak their way from coast to coast. Last September, Boeing said it would start outfitting all new 747-8 and 777 jets for mobile phone use by the end of 2013. The equipment, which fits in a single overhead compartment, provides a satellite link and a miniature cellular base station, or picocell. Several airlines are now working with telecoms to let passengers make calls and send text messages. Some, such as Virgin Atlantic, already offer the service on select flights for up to six passengers at a time; future systems will accommodate 30. Travelers can expect to pay international roaming rates to connect in the air. —ARIEL BLEICHER

THE DO-IT-ALL DISPLAY

CAN OIL DROPLETS CURE DISPLAY DISMAY?

By Glenn Zorpette

CHANCES ARE you spend far more time looking at electronic displays than at anything else, including your spouse's face. Yet though they dominate our lives and bring their manufacturers billions of dollars in revenue, displays are still pretty lousy, especially in mobile applications.

Liquid-crystal displays (LCDs) are heavy power hogs and practically useless in daylight. E-paper displays, which dominate e-readers, are light, readable even in direct sunlight, and parsimonious with power, but they can't display colors or change fast enough to handle video.

A display that combines the best features of LCDs and e-ink has long been a major goal [see "Lite, Brite Displays," *IEEE Spectrum*, March 2010]. This year, one of the best and brightest of the dozen or so contenders should finally make its commercial debut.

It's based on electrowetting, a trick that uses an applied voltage to alter the "wetness" of a surface, making a film of oil either spread out or bead up. If the oil is opaque, it'll act as a shutter to turn a pixel on or off in a tiny fraction of a second.

The Korean technology colossus Samsung will be the first to market a display based on electrowetting, having acquired the technology when it bought Liquavista, a Philips spin-off, in 2010. A similar approach is also being pursued by Gamma Dynamics, a start-up in Cincinnati that's commercializing technology developed at the University of Cincinnati.

It is in demanding mobile applications that the display's diverse strengths will be most apparent. With electrowetting, the same display could go from beach to bedroom, and it could handle books, magazines, videos, and Web-surfing in vivid color—all while economizing greatly on battery power. Further in the future, electrowetting might even deliver the long-sought "roll-up" display, a bauble in recent sci-fi films, which could roll or fold an iPad-size display into an iPhone-size housing.

JOHAN FEENSTRA flips a switch on a big light box and a half dozen experimental electrowetting displays come to brilliant, riotously colorful life. For Feenstra, who cofounded Liquavista and is now the CEO of Samsung's R&D Centre in Eindhoven, Netherlands, these are heady times. He's on the verge of learning whether the technology he has nurtured for the past 13 years can carve out a hunk of the vast market for efficient, full-color displays.

In the light box, the physical evidence seems compelling enough. There are seven panels, ranging from a diagonal of 7 inches to the iPad's 9.7 inches. On several of them, still pictures flash by while the others run videos. The colors are strong and clear, and the motion is smooth and free of lagging or blurring. The demonstration is all the more impressive because none of these panels is backlit. They all

SAMSUNG (3)

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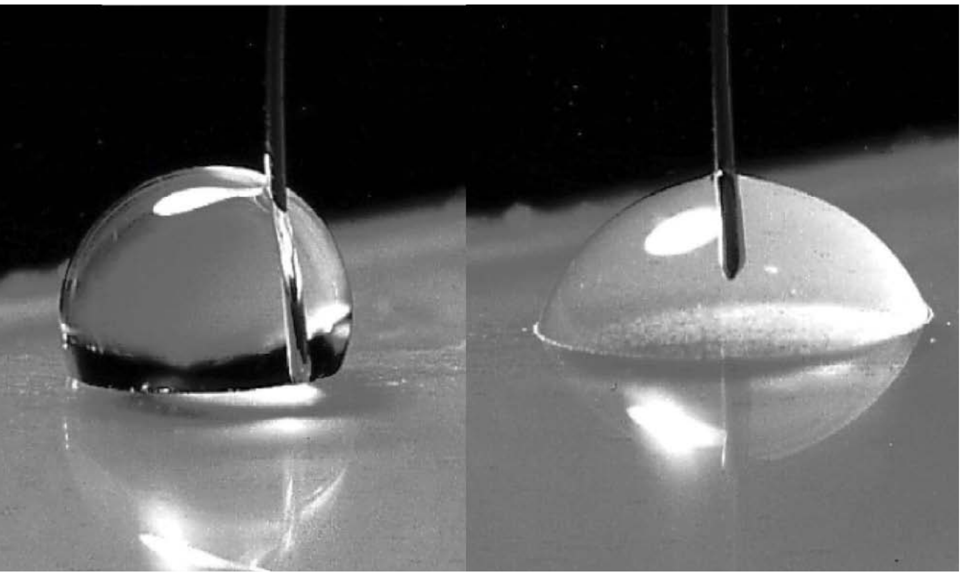

THERE'S OIL IN THEM THAR DISPLAYS: Electrowetting displays use a bead of oil as a shutter to turn pixels on and off. Because they don't need polarizing filters, they are much more efficient than LCDs, both in color [far left] and monochrome. Above, the basic principle is demonstrated: A water droplet on a hydrophobic surface beads up [left] but spreads out when a voltage is applied [right].

reflect light from the light box's fluorescent tubes, and therefore run at perhaps one-tenth of the power that backlit LCDs would need.

The LCD—that is, the thin-film-transistor liquid-crystal display—is one of the great inventions of the 20th century [See "How RCA Lost the LCD," *Spectrum*, November 2012]. But it has its weaknesses. A typical LCD screen consists of many optical and electronic layers, at the bottom of which is the backlight. Above it are two filtering layers that polarize its light—the first at one angle, the second at an orthogonal angle. That one-two polarizer punch effectively blocks any light from getting through.

However, in between the polarizers lies a layer of liquid crystals. In this layer, when a voltage is applied to a tiny area, called a subpixel, the liquid crystals rotate the polarization of the light from the first filter, so that it is no longer at a 90-degree angle with respect to the second polarizer. This allows at least some light to get through. If the display is a full-color one, this subpixel also has a red, a green, or a blue filter, which means that this colored subpixel can be turned on or off by simply applying a voltage to it. This is how the display's thousands or millions of subpixels create full-color images.

The problem is that the polarization limits both the viewing angle and the light coming from the backlight. Together, those optical layers—the polarizers, the color filters, and so on—waste more than 90 percent of the backlight's output.

ELECTROWETTING LIMITS this loss by dispensing with the polarizers. In one version, the light coming through a subpixel is controlled by an opaque black oil. Think of this subpixel as a square, shallow cup. It is filled with water, and there's a film of black oil spread over the cup's bottom, which is a transparent insulator. Underneath the insulator, sandwiched against it, is a transparent electrode. When a voltage is applied to that electrode and across the insulator, electrostatic forces cause the black oil to form a tight ball in a corner of the "cup." Now light can stream through the subpixel, except for the tiny bit blocked by the ball.

Though they use different "shutters" to control light, electrowetting displays and LCDs share many components, including the backplane containing the thin-film transistors that turn the voltage on and off at each subpixel. This has two big attractions: First, electrowetting displays can take advantage of many of the breakthroughs in the world of LCDs, such as the new indium gallium zinc oxide backplanes [see "Reformulating Displays," *Spectrum*, September 2012]. Second, they can be manufactured on existing LCD fabrication lines, with modest alterations. According to Feenstra, 90 percent of his pilot fab line in Eindhoven is a standard LCD setup.

Electrowetting displays can be backlit, like most LCDs are, or use reflected light—or even be front-lit, like the newest e-readers. Feenstra says that in backlit mode, his displays use a third as much power as a conventional LCD. That savings would double the life a tablet gets on a charge, Feenstra asserts.

Feenstra declined to say what Samsung's initial targets would be, but he singled out reflective-mode applications as "an interesting commercial opportunity." Other than that, he would say only that "the current display industry is very mature, and flat in terms of revenue growth. So rather than target existing markets, we are looking for whole new markets—ones where there is a gap that can't be fulfilled by existing technologies."

Gamma Dynamics, meanwhile, is betting that e-readers will be early converts. Jason Heikenfeld, the company's principal scientist, says that it is working on an electrowetting display in the form of an adhesive film that manufacturers could quickly and easily laminate to a backplane to produce a working display. E-ink displays are commonly produced this way, so the film would let an e-reader maker switch to electrowetting with minimal risk. Heikenfeld, who is also an associate professor of electrical engineering at the University of Cincinnati, reports that the technique has already paid an unexpected dividend: "This new film approach extends the brightness to true paper-white levels," he says.

Can electrowetting compete successfully against the established displays? This year, the picture will become clearer. ■

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2013 TECH TO WATCH

WATSON GOES TO MED SCHOOL

IBM'S AI PROGRAM MASTERED "JEOPARDY!" NEXT UP, ONCOLOGY

BY ELIZA STRICKLAND

ILLUSTRATION BY EDDIE GUY

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IBM

IN THE FINAL ROUND OF A TELEVISED GAME SHOW THAT PITTED TOP PLAYERS AGAINST IBM'S AI PROGRAM WATSON, A HUMBLED HUMAN JOTTED DOWN AN ASIDE TO HIS WRITTEN RESPONSE: "I FOR ONE WELCOME OUR NEW COMPUTER OVERLORDS."

Now even doctors are speaking that way. "I'd like to shake Watson's hand," says Mark Kris, an oncologist at Memorial Sloan-Kettering Cancer Center, in New York City. He talks excitedly about the day in late 2013 when Watson—now his student—will be fully trained and ready to assist physicians at the cancer center with their diagnoses and treatment plans.

It will be quite a career move for Watson, but one that IBM scientists envisioned from the get-go. They hope health care will be the killer app for Watson, an AI with phenomenal skills in natural-language processing. Watson first demonstrated its powers on "Jeopardy!," a game that employs puns and wordplay in its trivia clues. For each clue, Watson had to make sense of the messy English language, parse complicated phrasing, and search through up to 200 million pages of text.

Soon, after the equivalent of medical school, Watson will be able to examine a patient's history and test results, search the medical literature, and make a recommendation for the patient's treatment. To make the task manageable, the computer program's studies have so far been limited to oncology: Watson is studying lung and breast cancer now and will start on several other cancer types soon.

Kris, a lung cancer specialist, is working with the IBM team on the first iteration. The project is an experiment on the frontiers of medicine and technology, Kris admits, but he thinks it will result in a practical tool. He notes that for many cancer cases today, it's not obvious which chemotherapy drug will be most effective. "Sometimes it's very clear-cut; there's a genetic change, so you give the drug targeted to that genetic change. But for the vast majority of patients today, there isn't an obvious biology-linked treatment," Kris says. "We have many medicines that can help, and making the best choice can make a big difference for a patient."

That's where Watson can come in. It can comb through thousands of similar cancer cases and examine patient outcomes, review the most recent findings from hundreds of medical journals, and make a recommendation. The goal, Kris explains, is to replicate the decision-making process of a Sloan-Kettering oncologist. "Let's say you have an oncologist in Smalltown, U.S.A. Suddenly he has access to every medical journal

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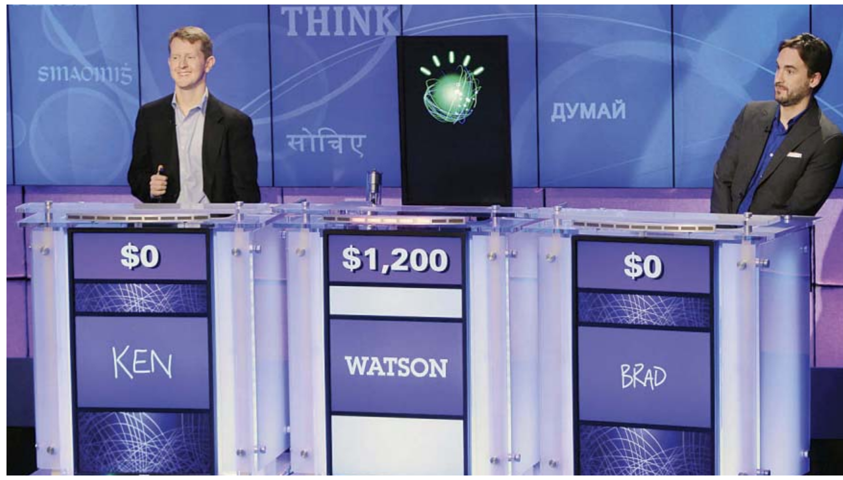
WATSON'S BRAIN [left]: At IBM's research facility in Yorktown Heights, N.Y., 90 servers are dedicated to the Watson project.

THE CHAMPION: Watson beat its human competitors soundly in two "Jeopardy!" matches, which aired in February 2011.



SETH WENIG/AP PHOTO

and the expertise of the top specialists at Sloan-Kettering," Kris says. Watson will never replace a human physician, Kris stresses, but it can provide advice and a top-notch second opinion. "It's a great tool for the doc," he says, "and for the patient it's a great comfort."

IN THE GAME SHOW face-off, Watson was positioned between the two most successful "Jeopardy!" players of all time. On its animated avatar, the whizzing beams of lights around the IBM "smarter planet" logo usually glowed green, indicating that Watson was on a winning streak.

The program parsed the game's complex clues with ease. For example, a clue in the category "Literary Characters APB" read: "Wanted for a 12-year crime spree of eating King Hrothgar's warriors; officer Beowulf has been assigned the case." In its choppy, computerized voice, Watson replied correctly: "Who is Grendel?" A panel at the bottom of the screen showed TV viewers Watson's top three search results along with its level of confidence for each. When it named the monster that devoured the king's men in the epic poem *Beowulf*, Watson was 97 percent confident.

The IBM Research team knew that Watson couldn't win at "Jeopardy!" by virtue of a know-it-all database alone. The program also had to learn how to interpret a complicated clue. As a child does, it had to learn how to understand. But IBM didn't have time to explain the world to a computer program, so it used sophisticated machine learning techniques to get Watson up to speed. The program was given tens of thousands of "Jeopardy!" clue-and-response pairs so it could establish its own rules for what constituted a correct response. Then it was tested with new clues. When it got an answer right, Watson took note of which algorithms had produced the correct search path and answer.

Martin Kohn, chief medical scientist of care delivery systems at IBM Research, says a similar process is now under way at Sloan-Kettering. "It will be given cases and treatment guidelines, and it will give its suggestions," Kohn says. Just as in "Jeopardy!," Watson will come up with a ranked list of possible solutions and display its confidence level for each. "Then one of the oncologists will say, 'Yes, what Watson suggested was reasonable' or 'Watson was off the wall,' " Kohn says. In that way, Watson will learn, and it will establish its credibility.

Right now, the Sloan-Kettering team is giving Watson cases that have all the information needed to devise a treatment plan, says Ari Caroline, Sloan-Kettering's director of strategic initiatives and quantitative analysis, who has been overseeing Watson's machine learning process at the cancer center. A next step is to give the program incomplete cases and get Watson to notice what's missing.

"Watson could actually prompt the user," says Caroline. "It could say, 'I can give you an answer with 30 percent confidence right now, which is not very useful. In order to give a more confident answer, you would have to provide the molecular pathology information around these particular tests.' "

DURING WATSON'S triumphant performance on "Jeopardy!," David Ferrucci, IBM's principal investigator for that project, spoke about the company's motives for investing heavily in Watson. "It is irresistible to pursue this," said Ferrucci, "because as we pursue understanding natural language, we pursue the heart of what we think of when we think of human intelligence."

Natural-language processing may be the gateway to a broad spectrum of applications, and IBM is already thinking of other business opportunities for Watson, like financial analysis. Yet the specialization required by "Dr." Watson is telling: IBM isn't aiming to make it a general practitioner, nor even an all-around oncologist, but rather an expert on a few types of cancers. In seems that each field of endeavor that Watson tackles brings with it its own specialized language and elaborate new problems.

No one knows that better than Caroline, who has worked on the details of Watson's medical training. "This is nothing close to a plug and play," says Caroline. "There's no such thing as a natural-language-processing tool that you just plug in and it automatically interprets everything."

But specialized though it is, Watson represents a big step in the direction of general intelligence, compared to IBM's earlier foray into world-beating, game-playing AIs. Its chess-playing system Deep Blue, which defeated then-world champion Garry Kasparov in 1997, couldn't do anything else, not even play checkers.

It remains to be seen whether Watson can build on its success, adding new realms of practical expertise, one after the other. The project shows the fascinating potential of machines that can speak our language, but it's also a reminder that we don't have to bow down to our computer overlords just yet. ■

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OLED TV ARRIVES

NEW DISPLAYS WILL BE BIG, BRIGHT, FAST, AND THIN—BUT NOT CHEAP

By Tekla S. Perry

FOR THE PAST DECADE, two television display technologies—liquid crystal and plasma—have fought for supremacy, and although the LCD won the battle, it is about to lose the war. A third contender's star is rising: the organic light-emitting diode, or OLED.

The thin, bright, beautiful, low-power OLED has been shining from the occasional cellphone or digital camera for several years now, but manufacturing problems kept its cost too high and its effective lifetime too short for consideration in big-screen TV.

This year, however, at least four major manufacturers think the time is right to sell 55-inch sets to consumers with cash to spare and an urge to own the latest and greatest gizmo. In a few years, OLED will reign supreme—at least until the next big technology comes along.

FIRST, A BRIEF REVIEW of the technology. OLEDs are semiconductors made of layers of organic material. They create light in much the same way as a traditional LED does: Electrons and holes meet and cancel each other out, releasing photons. Manufacturers make the screens by spraying organic films onto a substrate, typically glass or plastic, printing out patterns the way ink dots are printed on paper.

An LCD TV needs a backlight, but an OLED's pixels emit their own light. So turning them off makes them go completely black, with none of the afterglow you'd get from phosphor-based technologies—like cathode-ray tubes

DAVID PAUL MORRIS/BLOOMBERG/GETTY IMAGES

ILLUSTRATION BY L-Dopa

THIN IS IN: Samsung displays its 55-inch-diagonal OLED TV at the International Consumer Electronics Show in January 2012. The display measures just 7 millimeters thick.

or plasma displays—or even from an LED-backlit LCD, which can dim only regions of the screen, not individual pixels. Being able to create a really *black* black greatly improves picture quality.

And screens without backlights can be made very thin. Korean consumer electronics manufacturer LG has announced that its first 55-inch OLED TV will be just 4 millimeters thick and weigh 7.5 kilograms. A comparable 55-inch LCD TV from LG is nearly 4 centimeters thick and weighs about 22 kg.

OLED pixels can also be tiny and dense. Today's high-definition TV contains a grid of 1920 by 1080 pixels; broadcasters and manufacturers, however, are already talking about ultrahigh definition, or 4K resolution TVs, which typically boast 3840 by 2160 pixels. An OLED can manage that easily.

And OLEDs can switch on and off quickly enough to keep up with fast-moving images, which even the best LCDs tend to smear.

Finally, because they're printed, OLEDs can, in principle, be fabricated on flexible plastic substrates. Paul O'Donovan, principal research analyst for Gartner's semiconductor research group, says this could happen in as little as five years. He envisions a giant, wall-mounted TV screen that rolls up when not in use, so that it won't dominate the living room.

So far OLED screens have come only in small sizes, because manufacturing complexities ruined too many large screens, raising their unit cost. Over the years, companies have lowered the defect rate and have increased screen life by extending the time it takes for the blue pixels to fade to half their original brightness. That metric has risen from 5000 hours a few years ago to about 34 000 hours today at typical TV brightness levels, according to an announcement by DuPont. Though that's still a lot less than the 50 000 to 80 000 hours of an LCD, it's enough to allow an OLED TV to run about 18 hours a day for at least seven years.

Still, these large-screen OLEDs aren't going to be cheap. LG and Samsung, the other large Korean consumer electronics manufacturer, were to begin shipping 55-inch OLED televisions by the end of 2012. At press time, pricing had not been announced but was widely expected to be in the $10 000 to $13 000 range. So these early models won't exactly fly off the shelves. But, says O'Donovan, "I'm convinced both Samsung and LG will continue with OLED production even if it is a slow niche market for three to four years, because producing these will enable them to increase yields and put them several generations ahead of anybody else."

At least two other companies are scrambling to catch up. In 2012, Japanese companies Sony and Panasonic, usually bitter competitors, announced that they would pool their OLED technology to help them both start mass-producing 55-inch displays this year.

The companies are tackling the OLED in different ways. Samsung is using three OLEDs—one red, one green, one blue—for each pixel; LG is using white OLEDs throughout, creating subpixels with colored and white filters. O'Donovan says he thinks, at least in the short term, that LG's white OLED approach "will be better for yields and will create a more uniform color for the whole panel." He argues that although researchers have extended the lifetime of blue OLEDs to about 20 000 hours, white OLEDs eliminate the problem of fading blues altogether.

So this year you'll be seeing OLEDs in the stores and in the homes of early adopters—and that gorgeous, large, flat LCD TV you bought last January won't look state of the art anymore. ■

FAST-ACTION FLICKS

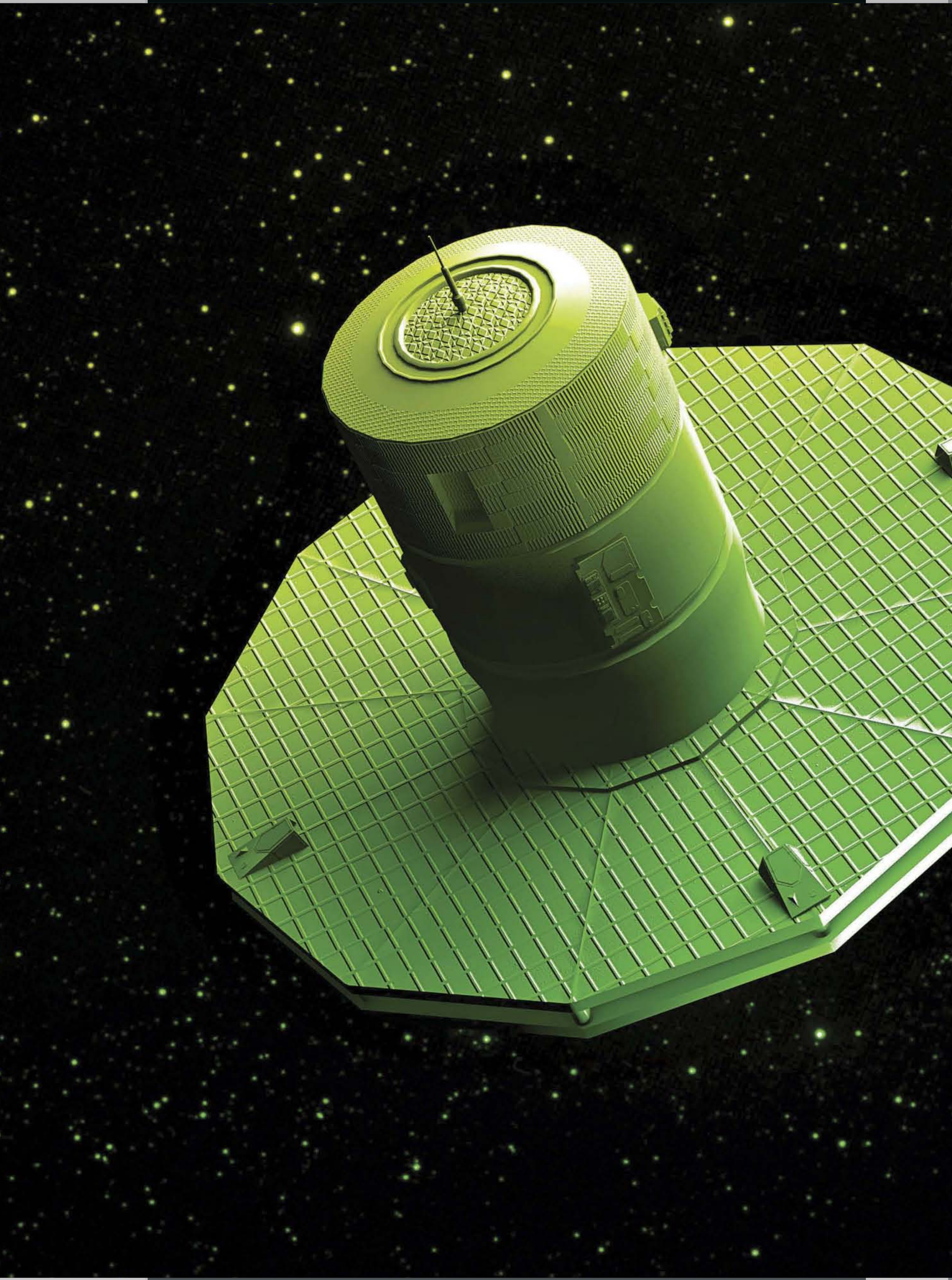
Filmmakers double the frames per second

Movies have changed a lot since the silent era ended in the late 1920s, but one thing has remained the same: the frame rate. From *The Jazz Singer* to *Avatar*, movies have run at an effective rate of 24 frames per second. Now, at last, that rate is starting to change.

The upgrade is being pushed by directors Peter Jackson, whose *The Hobbit* series is being shot at 48 frames per second, and James Cameron, who has announced that his forthcoming *Avatar* sequels will be filmed at a high frame rate. The speedup sharpens the rendition, particularly of fast, horizontal motion in moving images, but it's particularly useful in 3-D movies where such rendition often seems blurred or jerky.

Most digital projectors require only a software upgrade costing a few thousand dollars at most, according to Peter Ludé, senior vice president of Sony Solutions Engineering. "The big question is, will there be enough of a perceived benefit?" Ludé says. Three-dimensional and higher-resolution formats were a tough enough sell, he notes, and the improvement with a high frame rate is more subtle than with those other advances.

—GLENN ZORPETTE



2013 TECH TO WATCH

MAPPING THE MILKY WAY

EUROPE'S GAIA TELESCOPE WILL CHANGE HOW ASTRONOMERS VIEW OUR GALAXY

BY RACHEL COURTLAND

ILLUSTRATION BY EDDIE GUY

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ASTRONOMERS WHO STUDY THE MILKY WAY DON'T HAVE IT EASY. BOUND TO THE SOLAR SYSTEM, THEY'RE ON THE INSIDE LOOKING OUT, ALL THE WHILE WHIPPING AROUND THE GALACTIC CENTER AT ROUGHLY 900 000 KILOMETERS PER HOUR.

That's made it more than a little tricky to pin down fundamental details. It's still unclear, for example, how massive the Milky Way is and whether it's on a collision course with the nearby Andromeda galaxy. And there's still a lot of uncertainty about its basic structure. "There's been a pretty active debate in the last couple of years whether there are two or four spiral arms," says Mark Reid, a radio astronomer at the Harvard-Smithsonian Center for Astrophysics, in Cambridge, Mass. "That's pretty basic."

But the Milky Way could soon start coming into better focus. Later this year, a European Space Agency space observatory called Gaia will launch from a spaceport near Kourou, French Guiana. From a perch some 1.5 million kilometers from Earth, Gaia will spend five years scanning the sky, taking in starlight from all over the Milky Way and processing it at the rate of as many as 8000 stars per second.

The long-awaited €700 million mission aims to pin down the positions and velocities of a billion stars, about one out of every 100 stars in the galaxy. Those observations are expected to have a dramatic impact on our picture of the Milky Way. They should also significantly boost the accuracy with which we measure the distances to other galaxies, and by extension, the rate at which those galaxies recede from us as the universe expands.

"It's going to be phenomenal," says astronomer Barry F. Madore of the Carnegie Observatories in Pasadena, Calif., who works on astrophysical distance measures. The mission will be nothing short of "foundational," he says. "It will change everything."

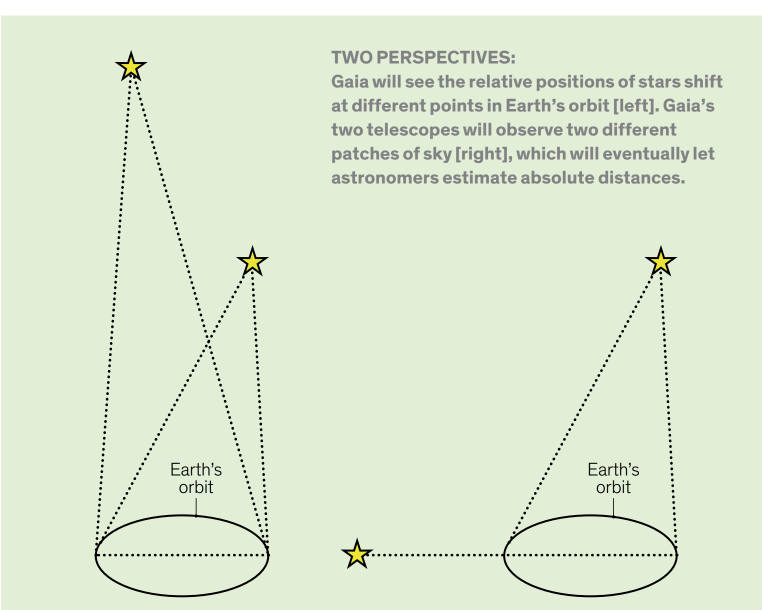
Gaia's main job will be to pinpoint the three-dimensional positions of stars. To measure distances—the trickiest component to pin down—Gaia is designed to be sensitive to parallax, the subtle shift in the position of an object against a background that occurs when the object is viewed from two different angles. You can see parallax in action if you hold a pencil in front of your nose and look at it with one eye closed and then the other. The farther away the pencil is from your nose, the smaller the change in position it exhibits with this change in perspective.

Because at interstellar distances these shifts in position are tiny, Gaia needs to change the viewing angle dramatically. It will do this by following a solar orbit similar to Earth's own and looking at the same patch of sky while on opposing sides of the sun. That method puts its "eyes" some 300 million km apart. By measuring frequency shifts in stellar spectra and subtle changes in position over time, the spacecraft will be able to get the three-dimensional velocities of stars as well.

For space fans fed on a steady diet of stunning Hubble Space Telescope images and news of supermassive black holes and record-setting explosions, stellar mapping might sound a bit stodgy. "People say it's not a very sexy topic," admits Gaia mission scientist Timo Prusti, but that's before they hear about Gaia's capabilities, he says.

Despite decades of effort, he says, precise distance measurements are still a rare thing; fewer than 1000 stellar distances are known with a precision of 1 percent. Gaia will be able to extend parallax measurements out much farther, measuring distances to more than 10 million stars with that same precision. "It's going to really be a sledgehammer in fundamental astronomy," Prusti says.

Gaia is only the second space mission dedicated to astrometry, the study of



TWO PERSPECTIVES: Gaia will see the relative positions of stars shift at different points in Earth's orbit [left]. Gaia's two telescopes will observe two different patches of sky [right], which will eventually let astronomers estimate absolute distances.

ICON BY L-Dopa

stellar positions and velocities. Such measurements were originally made from the ground. But about 50 years ago, improvements in precision began to run up against the limit set by atmospheric turbulence, which causes stellar positions to jitter and jump, says Michael Perryman, coproposer of the Gaia mission.

To get above the atmosphere, the European Space Agency launched a dedicated astrometric telescope called Hipparcos in 1989. Hipparcos was fairly rudimentary by modern telescope standards. For example, it was designed before charge-coupled devices (CCDs) were widely available; instead, it relied on a photomultiplier tube, which could measure only one star at a time.

Hipparcos was able to measure the parallaxes of nearly 120 000 stars with a precision of about a milliarcsecond, roughly equivalent to the angle subtended by an astronaut standing on the moon as seen from Earth.

Gaia's precision should be some 50 times that, or about what you'd need to see an insect crawling across the lunar surface. Part of the improvement comes from better detector technology. Instead of the photomultiplier tube, Gaia will launch with a bank of 106 CCDs measuring 1 by 0.5 meters, larger than any other focal plane yet sent to space. Each CCD boasts a high probability that an incoming photon will excite an electron and thus generate a signal, making it sensitive to very faint and distant stars.

To cover the sky, Gaia will spin once every 6 hours and precess about its axis once every 70 days. Because the spacecraft must accurately pinpoint its orientation at all times, it will maintain the timing of its spin with a precision of just 20 nanoseconds, using an onboard atomic clock. Gaia's spinning prevents it from operating in point-and-shoot mode. Instead, the CCD will gather up detected charge and pass it down the length of the detector as a star's image moves across it, in a read-out mode called time-delay integration. This technology has been used by other astronomy missions, including the Mars Reconnaissance Orbiter's High Resolution Imaging Science Experiment, to boost signals.

Like Hipparcos, Gaia will aim two main telescopes in different directions so that astronomers can get two independent perspectives on stars' positions relative to one another. After a good deal of analysis, the observations should lead to better estimates of the absolute distances from Gaia to the stars. To save space, the light from the two telescopes will be projected onto the same bank of CCDs. Two "sky mapper" detectors at the edge of the focal plane will be used to tag stars coming from each telescope so they can be followed as they sweep across the rest of the CCDs.

Long-term stability will be vital to achieving Gaia's targeted precision. Even microscopic changes in the size or shape of the mirrors, detectors, and supports can affect the positions of stars on the detector. So Gaia's designers built those parts from silicon carbide, a ceramic with a much lower coefficient of thermal expansion than the glass and aluminum used in Hipparcos.

To reduce thermal fluctuations even further, the observatory will be sent to the second Lagrange, or L2, point, where it will orbit the sun in tandem with Earth and therefore avoid flying in and out of Earth's shadow. Gaia will also carry a 10-meter-wide sun shield that it will unfold like an umbrella after launch to keep the observatory in permanent shadow, maintaining a constant temperature of -110 °C.

Gaia will have to contend with a great deal of obscuring dust in the plane of the Milky Way, which could make it impossible for the spacecraft to directly discern the galaxy's spiral structure, says Reid of the Center for Astrophysics. Nevertheless, astronomers expect that Gaia's observations of the visible parts of the sky will reveal more about the galaxy's structure and history, including the distribution of dark matter, the unseen stuff that helps bind the Milky Way together. In the course of scanning the sky, Gaia should also turn up new planets by finding stars that wobble due to the gravitational tug of orbiting bodies; more of the low-mass, "failed stars" called brown dwarfs that litter the galaxy; and new asteroids, including some that may potentially threaten Earth.

The mission is also expected to have a big impact on cosmology by helping better calibrate the "cosmic distance ladder"—the interlinked strategies astrophysicists use to estimate the distance to astrophysical objects. Many of these strategies ultimately depend on parallax, which is the only direct way astronomers have to measure distances in space.

One of Gaia's biggest contributions to this ladder could come from observations of two types of pulsating stars, Cepheids and RR Lyraes. These stars are often called standard candles because the period of their pulsation closely indicates their intrinsic brightness. By comparing that intrinsic brightness with the apparent brightness as seen from this

DARKNESS ILLUMINATED

New detectors will hunt for the fingerprints of dark energy

About 5 billion years ago, the universe began to expand more and more quickly, driven by a mysterious "dark energy." Space telescopes tailor-made to pin down dark energy's identity aren't likely to launch before 2019, but here on the ground the game is afoot. In 2013, the Dark Energy Survey will take full advantage of a custom-built, 570-megapixel camera now mounted on a 4-meter telescope at the Cerro Tololo Inter-American Observatory, in Chile. The scope will precisely measure cosmic expansion and help researchers to reconstruct the evolution of the universe's large-scale structure. A complementary experiment will be installed at the Hobby-Eberly Telescope in West Texas later in the year. —RACHEL COURTLAND part of the galaxy, astronomers can work out how far away the candle is.

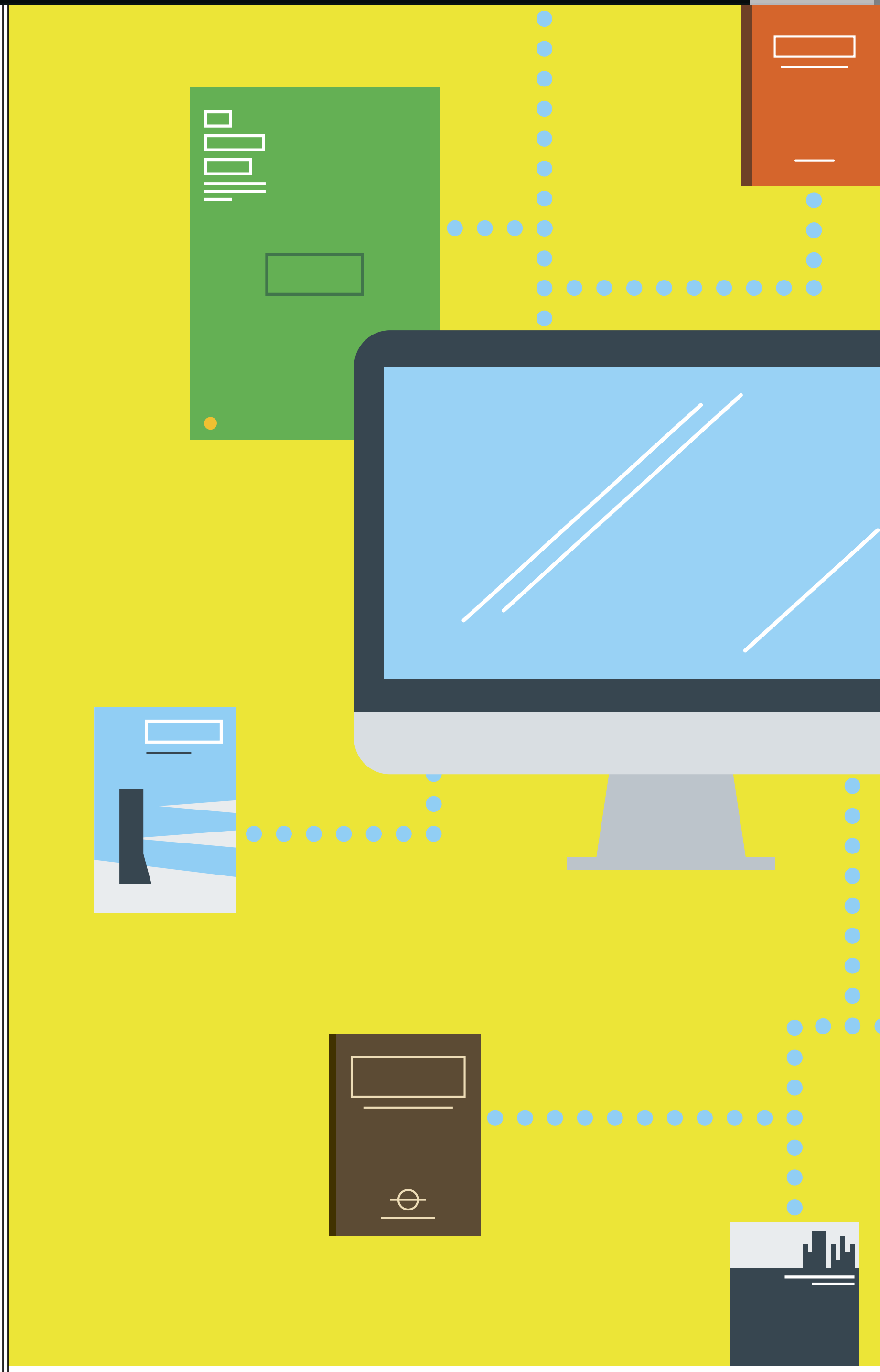
But to get a firm calibration of these standard candles, astronomers need an absolute way to measure distance, one that's independent of the physics of stars. In the last 10 years, a team led by Fritz Benedict of the McDonald Observatory, at the University of Texas at Austin, has used the Hubble's fine guidance sensor to measure parallaxes for the 10 Cepheids and 5 RR Lyrae stars closest to Earth.

Gaia, which will be able to see finer and more distant shifts in stellar position, should be capable of measuring distances to hundreds of Cepheids and thousands of RR Lyraes, Benedict says. That will give astrophysicists a much-improved stick by which to measure how fast the universe is expanding–a basic number that cosmologists need in order to calibrate the properties of distant objects and understand the composition and fate of the universe as a whole.

A better measure of the universe's expansion rate could, for example, help pin down the number of different types of neutrino species present in the universe, says Madore of the Carnegie Observatories. Analysis of radiation dating from just 400 000 years after the big bang, which depends on the expansion rate, suggests there may be four different flavors of the particles, but so far physicists have seen only three.

Whatever Gaia's impact, it will take a good three months for the spacecraft to travel to the Lagrange point and prepare for the start of science operations, and it will take lengthy number crunching to handle the data the craft returns during its five-year mission. Chances are, astronomers won't get to see Gaia's final results until 2021 or even later, more than 20 years after the mission was approved.

But many astronomers say it will be worth the wait. "It's been a century of second-guessing what the universe looks like and how bright things are and how far away things are," says Madore. "This [mission] will put concrete on the ground where before we were just sort of floating on logs on a mass of quicksand." ■

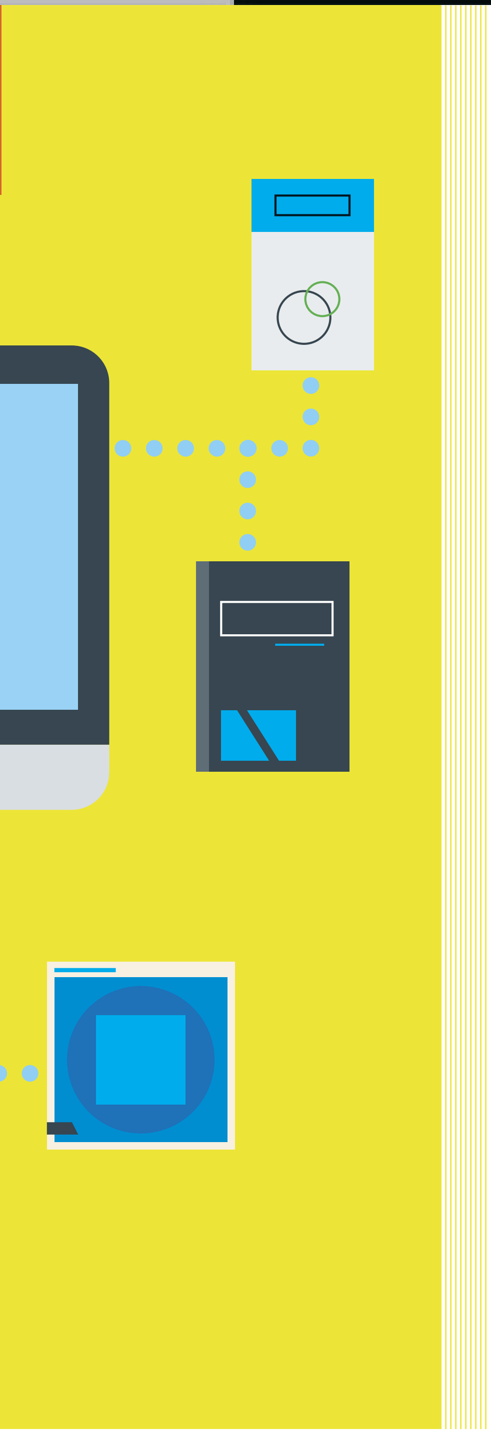


READ FREE OR DIE

HARVARD HOSTS A NONPROFIT ALTERNATIVE TO GOOGLE BOOKS

By Chris Thompson

ILLUSTRATIONS BY **L-Dopa**



IN 2004, Google decided to seek out millions of books gathering dust in library stacks, digitize them, and make them available to you at the click of a mouse. All you had to do was notice the advertisements in the margins.

But after Google extended its archiving effort from books in the public domain to those under copyright, the U.S.-based Authors Guild filed a class action lawsuit in 2005. Then, while negotiating a settlement, Google decided to sell not merely ads but the books themselves, with or without the specific consent of copyright holders, on the ground that the guild could stand in as their legal representative.

Not so fast, said federal judge Denny Chin, as he rejected one Guild-Google settlement after another. And as the case went forward, it raised a question in the minds of librarians, writers, and archivists: Should we really put the entire repository of human knowledge in the hands of one company?

In 2010, university librarians met in a national conference and decided to create an alternative called the Digital Public Library of America. Operating under the auspices of the Berkman Center for Internet & Society at Harvard University, it would archive every book in the public domain and offer them online to anyone. The library's prototype is expected to launch this year.

"This is a civic-minded engagement," says Kenny Whitebloom, who manages the library project. "There was a fear that Google Books was a commercial project, and this was an opportunity to create a digital library on its own terms."

The Digital Public Library has a lot of things going for it. It won't try to sell you ads when you read books online, and it won't try to sell books it doesn't have the right to. What it doesn't have is money–or at any rate not enough of it to scan and organize every book in the United States. (The rest of the world is a matter the organization will have to leave for another day.)

Instead, the Digital Public Library will serve as the archive for other archives. All around the country, from the Library of Congress to the Internet Archive in Northern California, libraries have been scanning books and setting up individual databases for their collections. The Digital Public Library of America hopes to produce a search engine that will coordinate with these institutions, creating a single search portal that will direct users to every single book they need, in any collection.

Whitebloom expects to finalize the legal deals with the various partners in the coming year. But if he gets the project going, he just might be able to offer what Google won't: words without ads. "It's free and open to all," he says, "a sustainable national resource that will not be beholden to commercial influences." ■

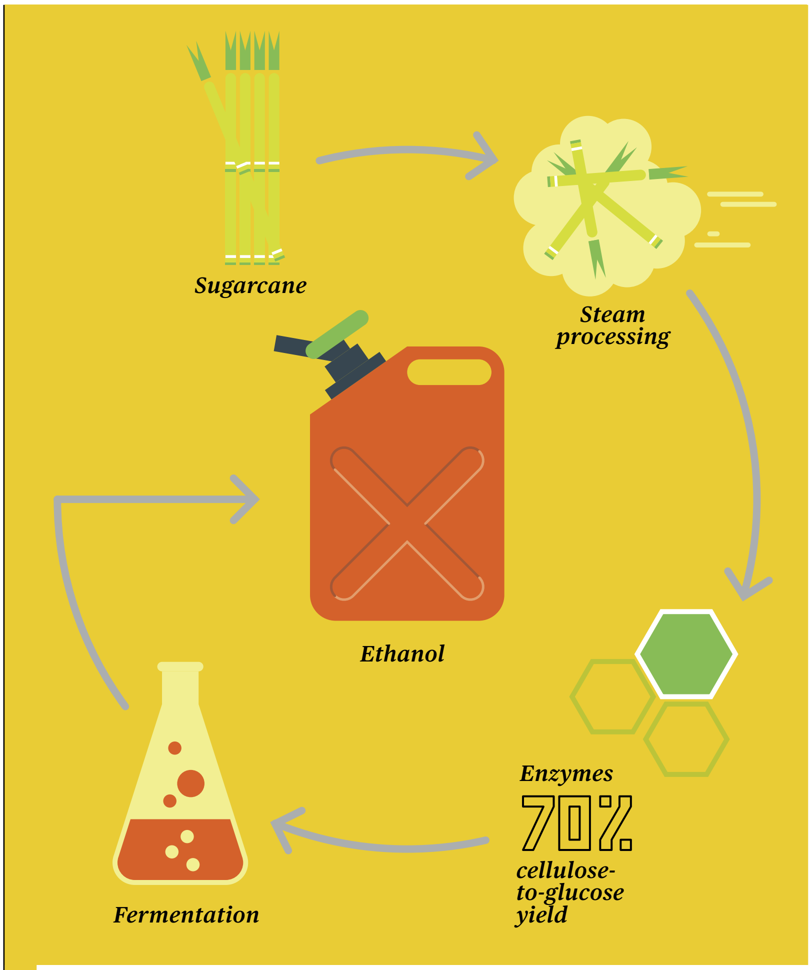
2013 TECH TO WATCH

A BOATLOAD OF ENTRE-PRENEURS

Unreasonable at Sea launches start-ups—literally

Reasonable people launch start-up accelerators—one-stop shops to find, fund, and foster entrepreneurship. But only an unreasonable person would launch one on a ship. Daniel Epstein, founder of the Unreasonable Institute, in Boulder, Colo., will embark this month from San Diego on a 100-day voyage that will visit 14 countries on a ship provided by the study-abroad program Semester at Sea. In return for the chance of accompanying him, 27 entrepreneurs have given him equity stakes in their start-ups, which build affordable medical products, fuel-efficient stoves, programmable hearing aids, drone sailboats that clean oceans, and other socially conscious products. Also on board for the Unreasonable at Sea cruise are mentors of all sorts. Epstein plans to cover his costs by bringing in folks who want to rub shoulders with the entrepreneurs and mentors. If that doesn't work, he'll have to find the funds later; he's already put a lot of expenses on his credit card. "My mom wasn't too excited about that," he says.

—TEKLA S. PERRY



BRAZIL DOUBLES DOWN ON BIOFUEL

A START-UP WANTS TO TRANSFORM SUGARCANE WASTE INTO CELLULOSIC ETHANOL

By Vinod Sreeharsha

LATER THIS YEAR, northeastern Brazil will host one of the most ambitious biofuel experiments ever. There, in the small town of São Miguel dos Campos, surrounded by sprawling sugarcane fields, a commercial-scale ethanol plant is expected to start operating in December. Unlike the nearby ethanol plants, which use sugarcane as feedstock, this new facility will consume the leftovers of those plants—bagasse and straw—to produce a holy grail of biofuel: cellulosic ethanol.

Ethanol produced from corn has gotten a bad reputation in recent years. Turning food crops into fuel might help drivers fill up their tanks, but it also raises food prices. What's more, studies have shown that production of corn-based ethanol actually increases carbon emissions rather than reducing them. Because cellulosic ethanol is made from agricultural waste and nonfood crops, it has none of those drawbacks.

The prospect of transforming cheap raw materials like sugarcane bagasse, switchgrass, wood chips, wheat straw, and corn stover into fuel has led to a worldwide race for technologies that can make cellulosic ethanol commercially practical. But success has eluded big companies and start-ups alike. It costs more to make ethanol from cellulose than from corn or sugarcane because of the extra equipment, chemicals, and steps involved.

Now a Brazilian start-up, GraalBio, thinks it can overcome those obstacles by combining state-of-the-art ethanol-processing technology from an Italian supplier, advanced biomaterials from a Danish firm, and the favorable conditions of the Brazilian state of Alagoas, whose large sugarcane industry produces abundant waste that it can use as feedstock.

The US $150 million facility that GraalBio is building will be South America's first and one of the world's only commercial-scale cellulosic ethanol plants. It's expected to produce 82 million liters (22 million gallons) of cellulosic ethanol per year, or more than 10 times the output of existing pilot and demonstration facilities. The plant is likely to be one of the world's most closely watched energy projects this year as the continuing instability in oil prices puts biofuels back in the spotlight.

Helena Chum, a research fellow with the U.S. National Renewable Energy Research Laboratory, says one of the advantages of the GraalBio

ILLUSTRATION BY L-Dopa

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project is that it includes "the whole cycle" of cellulosic ethanol production—from abundant feedstock to a large ethanol market. "This bodes very well for the field," she says.

Brazil's thirst for ethanol is perhaps greater than any other nation's. Nearly every car sold in the country has a "flex fuel" engine, capable of running on gasoline, ethanol, or any mix of both. But the country's much-praised ethanol program lost momentum when weak sugarcane harvests, low sugar stocks globally, and increased consumption worldwide brought surges in ethanol fuel prices. The Brazilian government didn't help, either: Its investments in biofuels slowed down after the discovery of massive offshore deepwater oil reserves. As a result, the country is struggling to meet domestic demand, with a deficit of 1 billion liters annually, according to one estimate.

That's the opportunity GraalBio wants to explore. It claims that using sugarcane waste as feedstock could expand the country's production by 35 percent. And how does the company plan to succeed where others have failed? In part, by acting as an integrator that combines the most advanced technologies available, says GraalBio founder and president Bernardo Gradin. According to Gradin, an engineer with a Wharton MBA and a former chief executive of Braskem, one of Brazil's largest petrochemical groups, there's no shortage of technologies out there. What the industry needs, he says, is more people willing to put the parts together and scale them up. "What we are trying to do is innovate the business model," he says.

Transforming cellulose into ethanol requires several steps. First you have to pretreat the biomass to break down its tough cellular structures, which typically involves processing with vast amounts of acids and other substances. Instead, GraalBio will use a chemical-free method that applies high-pressure steam to the raw materials to loosen up their cells. The company is licensing this technology, called Proesa, from Beta Renewables, owned by Italian conglomerate Mossi & Ghisolfi.

Next you need enzymes to break down the cellulose into simple, fermentable sugar molecules. It doesn't sound like high-tech stuff—cattle, sheep, and termites have such enzymes in their guts. But to process lots of feedstock cheaply, you need the best enzymes, and finding and tweaking them genetically has become a cutting-edge subfield of biotechnology.

One of the top companies in this area is Novozymes, based in Bagsvaerd, Denmark. About five years ago, the company's CTec2 enzyme had a glucose yield of up to 70 percent for corn stover but only about 30 percent for bagasse. More recently the company reported that its CTec3 enzyme produced glucose yields of about 70 percent for both corn and bagasse. That's the enzyme GraalBio will use.

And using sugarcane waste is just the beginning. The company hopes to create a new variety of cellulose-rich cane by crossing varieties of sugarcane with select types of grass. This "energy cane" could produce 300 metric tons of biomass per hectare in comparison to the 80 metric tons produced by regular sugarcane, says Gonçalo Pereira, the company's chief scientific officer, who runs GraalBio's newly built research center in Campinas, about 100 kilometers northwest of São Paulo. Pereira is also developing the company's own yeast strains, hoping to boost the fermentation process. And a new, improved water waste process and biomass storage will allow GraalBio's mills to run for most of the year, unlike traditional ones. These and other advances will be critical, Pereira says. "There will be companies that use the exact same biomass, and one will be profitable and one will be a disaster."

Still, it's a bold gamble, given cellulosic ethanol's history. Several attempts at large-scale production have ended up in failure in the United States, Canada, and other locations. GraalBio is confident in the success of its first plant. So confident, in fact, that it's already planning to build five more plants by 2017. The Brazilian government will help with financing. The Brazilian Development Bank recently tripled its budget for advanced biofuels to $1.5 billion and approved projects from 25 companies, GraalBio among them.

"People spent a lot of money on [cellulosic ethanol] and have not seen any results," says Arnaldo Vieira de Carvalho, a senior energy specialist at the Inter-American Development Bank in Washington, D.C. More recently, he adds, the technology has gotten cheaper, so new plants have a better chance at succeeding. "But given past experience, I take the wait-and-see approach." ■

SWEET FUEL: Conventional ethanol mills use sugarcane feedstock from farms like this one in São Paulo. Start-up GraalBio wants to use the leftover bagasse to produce cellulosic ethanol.

MARCO POMARICO/GRAALBIO


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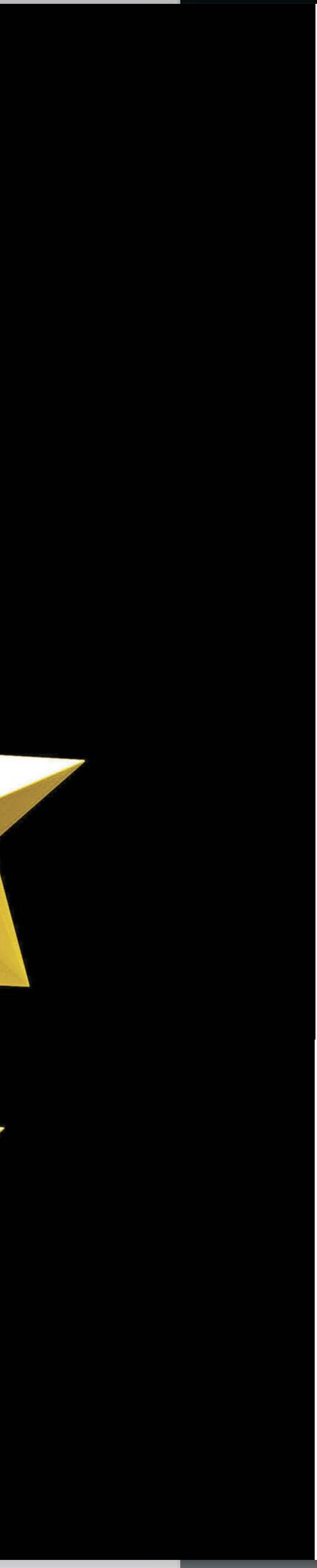

2013 TECH TO WATCH

INTEL INSIDE...YOUR SMARTPHONE

THE CHIP GIANT MAY FINALLY GET A GRIP ON THE MOBILE MARKET

BY KATHERINE BOURZAC

ILLUSTRATION BY EDDIE GUY

FOR A LONG TIME, THE MESSAGE FROM SMARTPHONE MAKERS TO INTEL COULD HAVE BEEN SUMMARIZED IN A SHORT TEXT: "UR DOING IT WRONG."

Nearly five years after introducing its Atom line of chips for mobile applications, Intel is still just a bit player in that business. In 2011 it produced only 1 million of the 760 million chips sold for use in mobile devices like tablets and smartphones, according to the Linley Group. Although Intel has since made some new inroads, no significant improvement is projected for 2012.

The reason? Early Atom chips were essentially just stripped-down standard processors, too costly and power hungry to compete with the products of established mobile chipmakers like Qualcomm and Broadcom Corp. Maybe Intel just didn't care, lulled as it was by the fat profit margins of its PC- and server-chip businesses.

Well, now it cares. PC sales are down, mobile sales are booming, and this year Intel will introduce a line of Atom chips, code-named Silvermont, that analysts say will at last be truly optimized for low-power operation. Intel itself is saying very little.

The company's actions speak louder than its words. Over the past few years, Intel has spent more than US $1 billion buying and licensing intellectual property for wireless circuits, image processing systems, and other parts for smartphones; inked partnerships with smartphone and tablet makers like Motorola Mobility and ZTE Corp.; and begun collaborating with Microsoft and Google to create chips that work well with their mobile operating systems.

One of the few things Intel has revealed is that Silvermont will have an entirely new microarchitecture—the circuit-level set of designs that determine how fast a chip can operate and at what energy cost. What's still unknown is exactly how much the microarchitecture will change and whether it will be enough to make Intel a big mobile contender.

Over the years, Intel's mobile design philosophy has evolved to look more like the one that has taken its competitors to the top. The main mobile processors use a design called system-on-a-chip (SoC), which pairs a central processor with specialized circuits for communications, graphics, navigation, and other tasks. SoCs save energy because they use dedicated systems that are packed closely together.

The early Atom chips relied instead on a general-purpose processor to perform all these tasks, with correspondingly poor power performance. The typical power budget for the main processor in a smartphone is 1 watt; the original Atom used that much even in an idle state. "They were trying to optimize for smartphones, but they didn't have too much experience," says Linley Gwennap, who heads the Linley Group.

But it seems Intel has learned its lesson. In 2012, it released the first Atom chip with a system-on-a-chip design, code-named Medfield. Shreekant Thakkar, an Intel Fellow and the chief platform architect in Intel's Mobile and Communications Group, says the new chips burn no more power than do chips made using schemes developed by ARM Holdings, the British firm that licenses basic circuit designs to nearly every smartphone processor maker. The new chip has been attractive enough to be picked up by Motorola and Lenovo Group, among others. The first smartphones with Intel inside shipped in 2012.

Although Medfield is built using the company's older, 32-nanometer manufacturing process, that was good enough to let Intel leave its power-hogging problems behind. But, says Gwennap, being as good as the established product isn't good enough. "You have to be as good and find one thing you can do better," he says.

That may be where Intel's signature advantage in manufacturing comes in. The company has typically led the industry, releasing next-generation chips with finer features—and thus faster and less-power-hungry transistors—sometimes years before everyone else.

So far, Intel's mobile chips have lagged a couple of years behind Intel's speediest microprocessors, Gwennap says. The company's most advanced chipmaking lines have traditionally been dedicated to churning out higher-margin PC and server chips, producing mobile chips once the initial investment in the manufacturing process has been more or less paid off.

Silvermont has been put on an accelerated schedule; it will emerge from Intel's top-of-the-line 22-nanometer fab only a year or so after the company's top microprocessors. That could give Intel a considerable edge in power consumption; the company says that its 22-nm Atom chips, all else being equal, will consume at least 30 percent less power at the transistor level than its 32-nm predecessors. Foundry giant Taiwan Semiconductor Manufacturing Co. (TSMC), which makes chips for many of Intel's competitors, is a generation behind; the Taiwanese firm didn't begin shipping 28-nm chips, which are roughly equivalent to Intel's 32-nm chips, until 2012.

But Intel may need more than manufacturing prowess. It's one thing to have the smallest, most efficient transistors. It's another thing to put them together into a speedy, energy-efficient package. Analysts say Intel has been at a significant disadvantage because it has created its Atom chips by paring down a microarchitecture that was designed for PCs rather than building the chips from scratch. To compete, Intel will likely have to overhaul its microarchitecture and work hard to optimize it to run Android, Google's operating system for mobile devices, as well as mobile versions of Windows. Intel has said it is working with both companies on its mobile offerings.

Other challenges lie outside the processor. "A smartphone contains much more than a microprocessor: It contains a variety of accelerators for graphics, video, audio, wireless, GPS—all of which are complicated pieces of hardware," says Arvind, a professor of computer science and engineering at MIT (who goes by one name). Intel's microprocessor prowess, says Arvind, "can be easily overshadowed by a company with inferior technology if that company offers a more complete solution for smartphone or other mobile devices than Intel does."

Intel wouldn't reveal a thing about the redesign of Silvermont. So we asked outsiders who are in a position to make an intelligent guess.

When asked to daydream about future Atom chips, Subhasish Mitra, an associate professor of electrical engineering and computer science at Stanford (and former Intel employee), says he'd like to see the company use more so-called accelerators, microarchitectures that can break up programs into multiple chunks that run in parallel, or in other less straightforward ways, to go faster or save power or both. The original Atom chips already used some of these strategies, but he says they could be optimized for mobile software to get more bang.

Even with all the technology in place, Intel could still face a hard climb from the bottom of the mobile pack. The economics of the mobile chip industry can be unforgiving. Smartphone chips typically sell for a quarter to a third as much as a PC processor, says Sergis Mushell, an analyst at Gartner. Today's mobile chip giants have many years of experience at driving down costs, and they have the advantage of sizable market shares to make up for the tight margins.

But Mushell points out that Intel has something its competitors lack: vertical integration. Intel designs and fabricates its own chips, whereas other companies have to pay a foundry like TSMC. Although Intel has the added overhead of operating its own wafer-fabrication plants, it will continue to make higher-priced chips on the same equipment, which could help improve its margins in the mobile market.

Today's mobile giants could be facing an even bigger threat in 2014, when Intel says it plans to move all of its chips—for PCs, servers, tablets, and phones—to a 14-nm manufacturing process. The cost would be high, but the payoff could be higher still, if it puts the company two full generations ahead of the competition. If Intel pulls it off, it could be a formidable mobile competitor. ■

THE SONY PS4: LESS DAZZLE, MORE SOCIAL

THE BIG MAKERS OF GAME CONSOLES WILL RENEW THEIR RIVALRY, AND SONY HAS A CHIP ON ITS SHOULDER

By David Kushner

IT'S SHOWTIME in the video-game industry again. Nintendo, Microsoft, and Sony are getting ready to unveil their next-generation consoles, the machines that will be at the heart of their strategies for years to come. Nintendo made the first play, with the release this past November of the Wii U, its first system to support high-definition graphics as well as a touch-pad controller. Microsoft has yet to announce the successor to its popular Xbox 360, though a new console—rumored to be called the Xbox 720—is expected this year.

But forget that for now and consider Sony, which has the most at stake here and has watched its once leading PlayStation franchise lose ground in recent years. Sony used to dazzle with its technological daring, but it has been more than six years since it introduced the PlayStation 3, and the company now finds itself in a fundamentally altered gaming universe, in which technological dazzle isn't nearly as important as it used to be. So there's more than the usual curiosity about Sony's long-awaited next flagship console, the PlayStation 4, which many insiders and analysts expect will be introduced later this year.

Sony hasn't confirmed that expectation, and there's very little hard information available. The only official word so far was a cryptic comment from Andrew House, chief executive of Sony Computer Entertainment, who said last June that "the right time to talk about new advances in hardware is when you can demonstrate a significant leap on the current experience, and something that is going to be attractive." House was speaking to the game-industry publication *MCV*.

So—will this leap be significant and attractive enough?

The bar is set high. The PlayStation 3 enthralled gamers with its radical microprocessor, the Cell Broadband Engine Architecture, or Cell, for short [see "Multimedia Monster," *IEEE Spectrum*, January 2006]. Sony, with partners Toshiba and IBM, spent an estimated US $400 million and took five years to create the Cell, which incorporated nine separate processors that were together capable of

192 billion floating-point operations per second. It ushered in an era of computationally brawny gaming, one characterized by crisply realistic graphics and robust artificial intelligence, as seen in games like *Call of Duty 3* and *Resistance: Fall of Man*.

But plenty has changed since the PS3's release. With the rise of Facebook and smartphones, the buzzwords in the industry have changed from "eye candy" and "AI" to "social" and "mobile." Hits like *FarmVille* and *Angry Birds* proved that being accessible, communal, and of course, fun is enough to win over both players and developers. "The platforms are not what defines the generations as much anymore," says Mark Rein, vice president of Epic Games, the Carey, N.C.-based developers of the Unreal video-game engine and the *Gears of War* game franchise. "We have so much hardware now and so many cool new things we can do, and so many devices with lots of power and memory."

It's a distinct possibility that Sony will abandon the Cell in the PS4. And if it does, not everybody will be sorry to see it go. "The problem with the whole Cell architecture was that it was really complicated," says David Cole, founder and president of DFC Intelligence, a technology research firm in San Diego. "It was difficult to program for and almost too advanced for its time."

Specifically, when programming the Cell, the demands of keeping track of nine distinct execution threads drove many programming teams to distraction. "If you expect to port your application efficiently to the Cell via recompilation or threads, think again," warned *Dr. Dobb's*, a popular journal for software developers [see "The Insomniacs," *Spectrum*, December 2006].

Many successful new games are coming from independent developers with few resources. So to be competitive, Sony needs to ensure that the next person who makes a cool game in a garage can easily port it to the PlayStation. "Sony wants to streamline the process," says Lewis Ward, research manager at IDC, a market research firm based in Framingham, Mass., "and make it easier to release games that are developed for the PC or tablet first and move to the PS4 platform."

The last generation of consoles made possible graphics and AI that could suspend a player's sense of disbelief. Now the challenge is to provide experiences that resonate with people who are used to being connected with each other online. As a result, what players are "not going to see is this large jump in graphic intensity," says Jesse Divnich, vice president of insights and analysis for Electronic Entertainment Design and Research, in Carlsbad, Calif. "Processing power will be dedicated to new features that power the back end: social interaction, multiplayer–stuff that will really drive gaming forward." Artificial intelligence will still be a priority, Divnich says, but it won't take precedence over digital distribution and community.

Sony has already begun pursuing a more social and interactive strategy. In July, the company paid a reported $380 million to acquire Gaikai, a cloud-based gaming service in Aliso Viejo, Calif. In addition to allowing video-game publishers to conveniently stream demos to players, Gaikai could let Sony deliver content to other devices, such as the PlayStation Vita, the handheld game system released in December 2011.

Gaikai's cloud service runs at 3 megabytes per second and faster, and Ward expects that when Sony integrates such digital distribution into the PS4 it "will be a big part of what [it] can do that the current generation can't do today." He also speculates that this cloud network will take advantage of the Xperia Play, a phone built on the Android operating system by Sony Ericsson Mobile Communications, before Sony's buyout of Ericsson's share of the joint company.

The significance of the Xperia Play phone is not to be dismissed. Utilizing a mobile device will allow for the kind of "dual screen" entertainment experience that will both rival Nintendo's Wii U and speak to players who are used to watching TV with a cellphone in hand. Ted Price, president and chief executive officer of Insomniac Games, makers of bestselling PlayStation franchises including *Ratchet & Clank*, says that while it "depends on the game," the "opportunity exists to use dual screens as a social mechanic." Two people playing a racing game, for example, could see an overhead view of the action on the TV while at the same time seeing a first-person POV, through the windshield, on their handheld screens.

Ultimately, it will be new and shared experiences such as this one that will decide who wins the next battle of the console wars. ■

OUYA OPENS UP GAME DESIGN

Its Android-based console lets anyone be a game developer

While mobile games may be all the rage, one start-up is betting that gamers miss the lush experience of playing on a big-screen TV. But Ouya, the sleek new gaming console shipping early this year, is hardly a retro throwback—in fact, it may be revolutionary. Its Android-based software is open source, which means anyone can develop games for the system. The company will use an app-store model, and it insists that any game developed for Ouya must have a free-to-play version.

Ouya generated deafening buzz in 2012 with a Kickstarter campaign that raised almost US $8.6 million. Still, a few big questions remain: Can it meet its deadlines? And will the open-source games grab gamers' interest? —ELIZA STRICKLAND

ILLUSTRATION BY L-Dopa

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UNIVERSIDAD DE INGENIERÍA & TECNOLOGÍA

Universidad de Ingeniería y Tecnología
Lima- Peru

Professors and research positions for engineering professionals

Description: We invite applications for professors and research positions for engineering professionals in the fields of Electronics (control and automation), Mechanics (design, manufacturing and materials), Chemistry, Computing, Systems, Industrial or Metallurgical .

We expected to build a world-leading research and educational University in the above mentioned areas.

Qualifications: Interested candidates should have a Ph.D. or Master´s Degree in the relevant areas.

Very good English written and oral communication skills. Spanish it is not required.

Work, teach and research experience in relevant areas research projects.
The applications with a detailed CV, research and teaching plan and list of preferences should be sent to: ***professor@utec.edu.pe***

BAYLOR UNIVERSITY

The Electrical and Computer Engineering Department of Baylor University

seeks faculty applicants for two Tenure-Track Assistant/Associate Professor Positions in all areas of electrical and computer engineering, with preference in the areas: embedded systems, computer/network security, software engineering, sensor networks, power, and energy. Applicants seeking a more senior position must demonstrate a record of sustained research funding. All applicants must have an earned doctorate and a record of achievement in research and teaching. The ECE department offers B.S., M.S., M.E. and Ph.D. degrees and is poised for rapid expansion of its faculty and facilities, including access to the Baylor Research and Innovation Collaborative (BRIC), a newly-established research park minutes from the main campus.

Chartered in 1845 by the Republic of Texas, Baylor University is the oldest university in Texas. Baylor has an enrollment of approximately 18,000 students and is a member of the Big XII Conference. Baylor's mission is to educate men and women for worldwide leadership and service by integrating academic excellence and Christian commitment within a caring community. The department seeks to hire faculty with an active Christian faith; applicants are encouraged to read about Baylor's vision for the integration of faith and learning at **www.baylor.edu/profuturis/**.

Application reviews are ongoing and will continue until both positions are filled; however, applications received by January 1, 2013 will be assured of full consideration.

Applications must include:

1) a letter of interest that identifies the applicant's anticipated rank,
2) a complete CV,
3) a statement of teaching and research interests,
4) the names and contact information for at least four professional references.

Additional information is available at **www.ecs.baylor.edu**. Send materials via email to Dr. Robert J. Marks II at *Robert_Marks@baylor.edu*. Please combine all submitted material into a single pdf file.

Baylor is a Baptist University affiliated with the Baptist General Convention of Texas. As an Affirmative Action/Equal Employment Opportunity employer, Baylor encourages candidates with an active Christian faith who are minorities, women, veterans, and persons with disabilities to apply.

ÉCOLE POLYTECHNIQUE FÉDÉRALE DE LAUSANNE

Faculty Position in Electrical Energy Generation, Conversion and Storage

at the Ecole Polytechnique Fédérale de Lausanne (EPFL)

The School of Engineering at EPFL invites applications for a **tenure-track assistant professor** position in the area of **Electrical Energy Generation, Conversion and Storage**.

Topics of interest include, but are not limited to, systems for electricity generation and storage. The candidate should have a strong background in electrical and/or materials engineering.

As a faculty member of the School of Engineering, the successful candidate will be expected to initiate an independent and creative research program and participate in undergraduate and graduate teaching. Internationally competitive salaries, start-up resources and benefits are offered.

The EPFL, located in Lausanne, Switzerland, is a dynamically growing and well-funded institution fostering excellence and diversity. It has a highly international campus at an exceptionally attractive location boasting first-class infrastructure. As a technical university covering essentially the entire palette of engineering and science, EPFL offers a fertile environment for research cooperation between different disciplines. The EPFL environment is multilingual and multi-cultural, with English often serving as a common interface.

Applications should include a cover letter with a statement of motivation, curriculum vitae, list of publications and patents, concise statement of research and teaching interests, and the names and addresses of at least five referees. Applications must be uploaded in PDF format to the recruitment web site: **energy-search13.epfl.ch**

Formal evaluation of candidates will begin on **28 January 2013**.

Enquiries may be addressed to:
Prof. John Thome
Search Committee Chair
e-mail: **energy-search@epfl.ch**

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

EPFL is committed to increasing the diversity of its faculty, and strongly encourages women to apply.

Carnegie Mellon ENGINEERING

Faculty Position

www.cmu.edu/rwanda

Carnegie Mellon University's College of Engineering (www.cit.cmu.edu) has opened an exciting new location in East Africa, focusing on the development and applications of information and communication technology (ICT). This regional Centre of Excellence (CoE) in Kigali, Rwanda, offers first-class graduate education in a region of the world booming with opportunities for technology innovation. Striving to become the technology hub for East Africa, Rwanda is investing heavily in infrastructure and capacity building in the critical areas of ICT and engineering.

With a history of excellence in higher education, Carnegie Mellon in Rwanda (CMU-Rwanda) is addressing the needs of Rwanda's and the region for highly skilled professionals by offering degree programs, the Master of Science Information Technology (MSIT) and, beginning in 2015, the Master of Science in Electrical and Computer Engineering (MSECE). The first class of CMU-Rwanda MSIT students enrolled in August 2012. Carnegie Mellon's College of Engineering is consistently ranked amongst the top ten in the USA and the world. The College includes seven academic departments granting BS, MS, and PhD degrees, two graduate-only degree granting departments (Information Networking Institute and Carnegie Mellon Silicon Valley Campus), several multidisciplinary research centers, and two Institutes (Carnegie Mellon CyLab, and Institute for Complex Engineered Systems).

Successful applicants for faculty positions with CMU-Rwanda will be expected to spend two academic semesters at Carnegie Mellon, Pittsburgh or Carnegie Mellon University Silicon Valley before assuming positions in Kigali.

Carnegie Mellon is seeking exceptional candidates who want to contribute to innovative, interdisciplinary graduate programs at CMU-Rwanda in the areas of networking, communications, cyber security and privacy, software engineering, mobile technology, cloud computing, energy systems, image and signal processing, embedded systems, eHealth, entrepreneurship, and innovation and technology management. Candidates must possess a PhD in CS, ECE or a related discipline, and an outstanding record in research, teaching and leadership. Applications should include a comprehensive resume, including a complete list of publications, a list of 3-5 professional references, statements of research and teaching interests (less than 2 pages each), and copies of 2 research papers (journal or conference papers).

Applications should be submitted by email to: Prof. Bruce H. Krogh, Director, CMU-Rwanda, Email: rwanda.coe@cit.cmu.edu

ÉCOLE POLYTECHNIQUE FÉDÉRALE DE LAUSANNE

Professorship in Energy Research

and Director of the Energy Center at Ecole polytechnique fédérale de Lausanne (EPFL)

The Swiss Federal Institute of Technology, Lausanne (EPFL, **http://www.epfl.ch**) is a world-class European Research University and a growing, dynamic, public institution of higher education with a focus on engineering, computer science & communications, basic and life sciences.

EPFL is launching an international search and invites applications and nominations for the position of Director of its Energy Center to take office no later than 2014. The center director will also be appointed in one of the academic departments and is expected to establish a strong research program in her/his own area in addition to managing the Energy Center. EPFL provides strong institutional funding to support the research of its professors.

The Energy Center formulates a strategy and coordinates energy research activities on campus, it maintains a strong link to industry and its director is EPFL's main spokesperson in the energy domain. The Center provides the interface to the Swiss and European governmental and funding agencies. A broad spectrum of research is currently ongoing at EPFL in electrical power generation (e.g., hydroelectric, photovoltaic, fuel cells, solar fuels, wind, biochemical, plasma physics), energy storage (e.g., hydroelectric, batteries), and power networks and systems.

Major new initiatives with new buildings and positions in photovoltaics (at Neuchâtel) and renewable energies (in Valais) are planned. The Swiss government has recently announced a major program to support energy research. EPFL is expected to be a key participant in this effort. The new Director of the Energy Center is expected to provide the intellectual and managerial guidance so that EPFL can help address the energy needs of Switzerland and the World.

The Director of the Energy Center will report directly to the VP for Innovation and Technology Transfer. The ideal candidate has an outstanding academic record, proven leadership, fundraising and negotiating skills, as well as knowledge transfer and management abilities.

The Search Committee invites applications (vision statement, complete CV and the names of at least 6 professional references) to be submitted at: **http://director-energyctr.epfl.ch**
Screening of dossiers will start **February 15th, 2013** and will continue until the position is filled.

Letters of nomination, expressions of interest or inquiries may be addressed confidentially to:

Professor Philippe Gillet
EPFL Provost & Chairman of the Search Committee
director.energyctr@epfl.ch

EPFL is an equal opportunity employer.

Joint Institute of Engineering

SUN YAT-SEN UNIVERSITY

Carnegie Mellon University

Sun Yat-sen University (SYSU) & **Carnegie Mellon University (CMU)** have established the **Joint Institute of Engineering (JIE)**, which will provide world-class education and cutting-edge research in China's Pearl-River Delta region, which provides rapidly growing opportunities for future technology innovation. JIE is seeking **full-time faculty** in all areas of Electrical/Computer Engineering. Candidates should possess a Ph.D. in ECE or related disciplines, with a demonstrated record and potential for research, teaching and leadership. The position includes an initial year on the Pittsburgh campus of CMU to establish educational and research connections before locating to **Guangzhou, China**. This is a **worldwide search** open to qualified candidates from all countries and of all nationalities, with an internationally competitive compensation package for all qualified candidates.

Faculty Positions Available *in Electrical/Computer Engineering*
Visit **http://sysucmuji.cmu.edu** *for details.*

UNIVERSITY OF MINNESOTA DULUTH

Jack Rowe Endowed Chair in Electrical Engineering

The Department of Electrical Engineering at the University of Minnesota Duluth is seeking candidates for the tenured position of Jack Rowe Endowed Chair. The Chair holder is expected to teach courses at both undergraduate and graduate levels, develop an externally funded research program, and establish a strong relationship with communities and industries of the region. A Ph.D. in Electrical Engineering or Electrical and Computer Engineering from a regionally accredited institution with a minimum of 10 years of combined research and teaching experience in academia and/or industry in the areas of Power, Energy, and Control is required. The candidates must have a distinguished national and/or international reputation in research or education with a strong record of obtaining external funding. Experience in working with students, staff, and faculty from diverse communities and cultures is highly desired.

Please apply online via the Employment System at
https://employment.umn.edu/applicants/Central?quickFind= 181509

Completed applications should include a letter of application, a research plan, a complete resume, and contact information of three professional references.

Applications will be accepted until the position is filled. University of Minnesota Duluth is an equal opportunity and affirmative action educator and employer and welcomes applications from women and minorities. For further information, please contact Search Chair Dr. Taek Kwon at ***tkwon@d.umn.edu*** or 218-726-8211.

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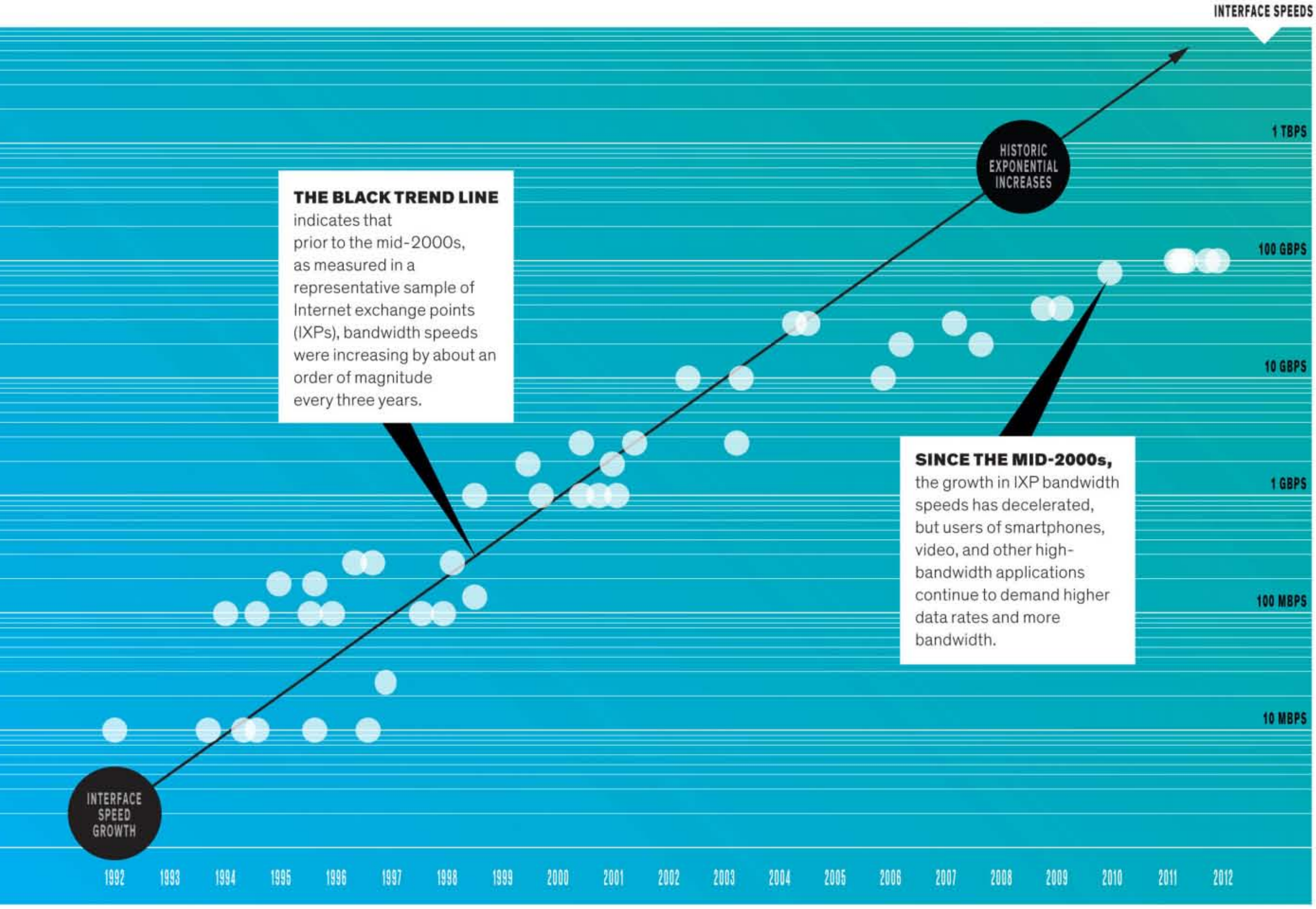
DATAFLOW_

BANDWIDTH BOTTLENECK

THE HARDWARE AT THE HEART OF THE INTERNET ISN'T FAST ENOUGH

The 2001 collapse of the dot-com and telecommunications bubbles was devastating to the companies laying fiber-optic communications cables. It also had a less-visible impact on that basic optoelectronic physics research that drives improvements in the speed and range of fiber-optic networks. ¶ It takes years for physics innovations to work their way out of the lab and into the market, but the pipeline filled by research in the 1990s dried up by the mid-2000s, and we're now seeing that the growth in the speed of fiber optic interfaces at Internet exchange points (IXPs) has slowed considerably. IXPs form the core of the Internet, where the bandwidth sold by ISPs is produced. This sluggish growth is constraining supply at a time when the global demand for Internet bandwidth is booming.

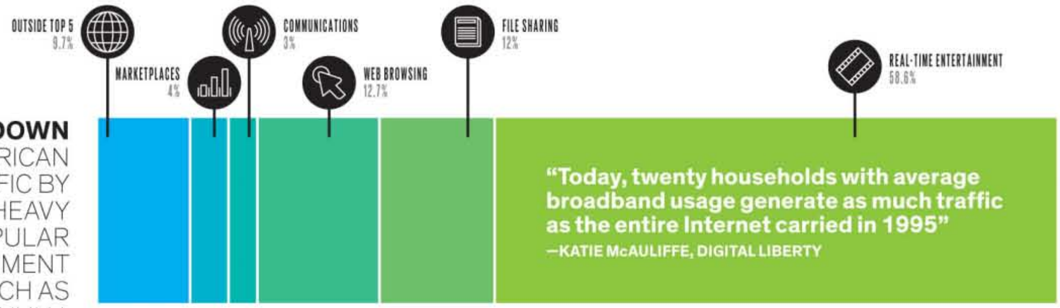
—DENNIS WELLER & BILL WOODCOCK



THE BLACK TREND LINE indicates that prior to the mid-2000s, as measured in a representative sample of Internet exchange points (IXPs), bandwidth speeds were increasing by about an order of magnitude every three years.

SINCE THE MID-2000s, the growth in IXP bandwidth speeds has decelerated, but users of smartphones, video, and other high-bandwidth applications continue to demand higher data rates and more bandwidth.

THIS BREAKDOWN OF NORTH AMERICAN INTERNET TRAFFIC BY USE SHOWS THE HEAVY DEMANDS OF POPULAR REAL-TIME ENTERTAINMENT SERVICES SUCH AS NETFLIX AND HULU.



Dennis Weller, an economist at Navigant Economics, and Bill Woodcock, the research director of the nonprofit Packet Clearing House, prepared the study on which this page is based for the Organisation for Economic Co-operation and Development (OECD).

SOURCES: PACKET CLEARING HOUSE; "INTERNET TRAFFIC EXCHANGE: MARKET DEVELOPMENTS AND POLICY CHALLENGES," OECD; SANDVINE (INTERNET TRAFFIC BREAKDOWN)

INFOGRAPHIC BY Carl DeTorres

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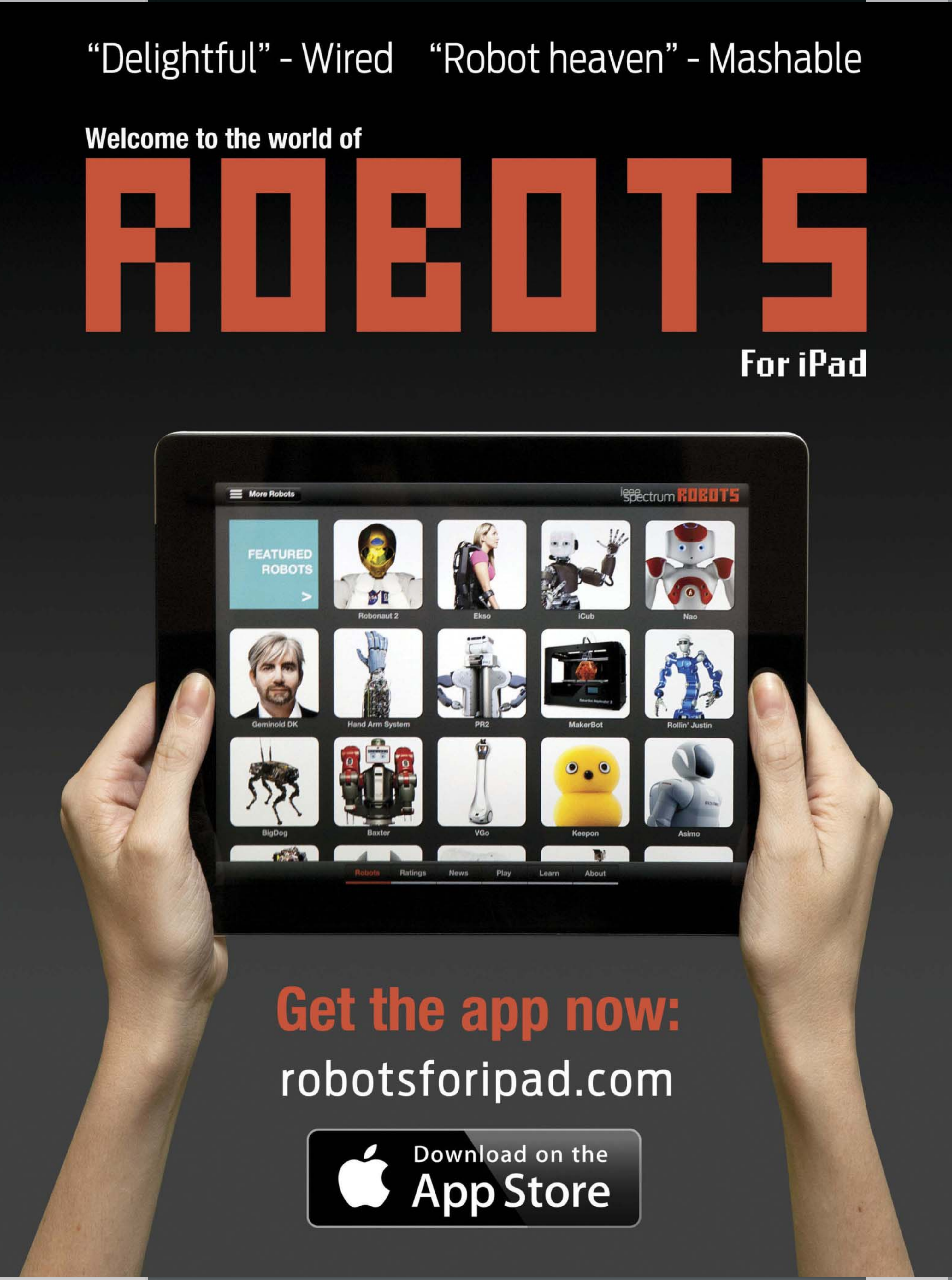
"Delightful" - Wired "Robot heaven" - Mashable
Welcome to the world of
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More Robots
spectrum ROBOTS
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Ekso
iCub
Nao
Geminoid DK
Hand Arm System
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