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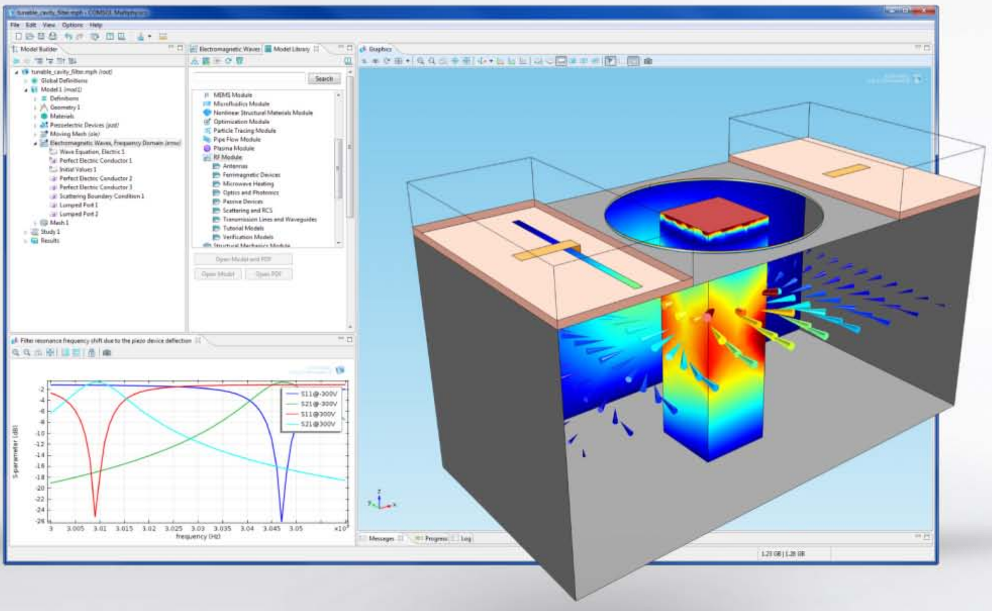

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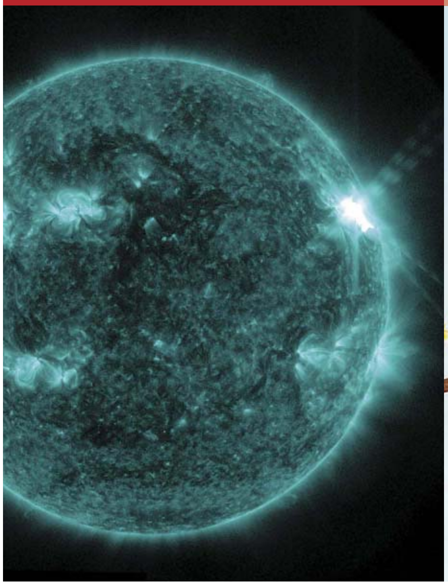

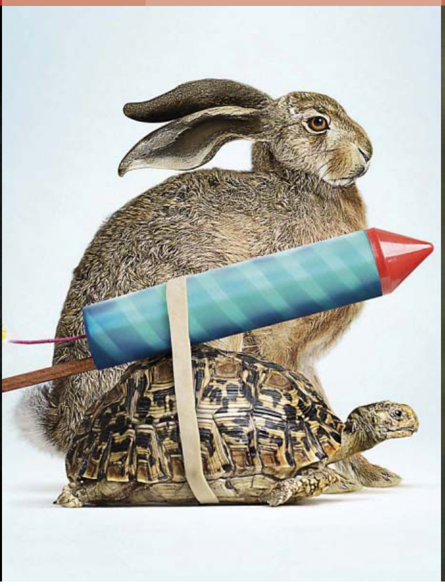

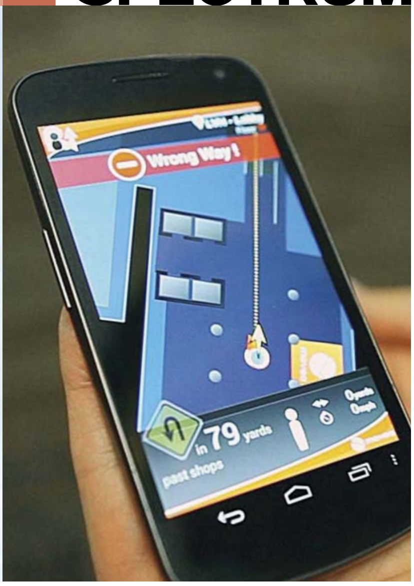

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IEEE WOMEN IN ENGINEERING TEAMS UP WITH GOOGLE IEEE WIE and Google recently held a two-day event aimed at supporting women engineers. "Enhancing the Sustainability of Women in Technology," held at the company's headquarters in Mountain View, Calif., drew more than 200 attendees.

STUDENT BRANCH SPOTLIGHT: RUTGERS UNIVERSITY The IEEE student branch at Rutgers University, in New Brunswick, N.J., has been busy with activities lately, including developing a robot.

SHED THE WIRES, SHED THE WEIGHT IEEE 802.3 physical-interface transceivers are used in vehicles to accommodate multiple entertainment and data systems. One IEEE standards group is working to reduce the number of wires required to run these applications, to pave the way for lighter, more fuel-efficient cars.

FROM LEFT: SOLAR DYNAMICS OBSERVATORY/NASA; GANDEE VASAN/GETTY IMAGES; CELIA GORMAN

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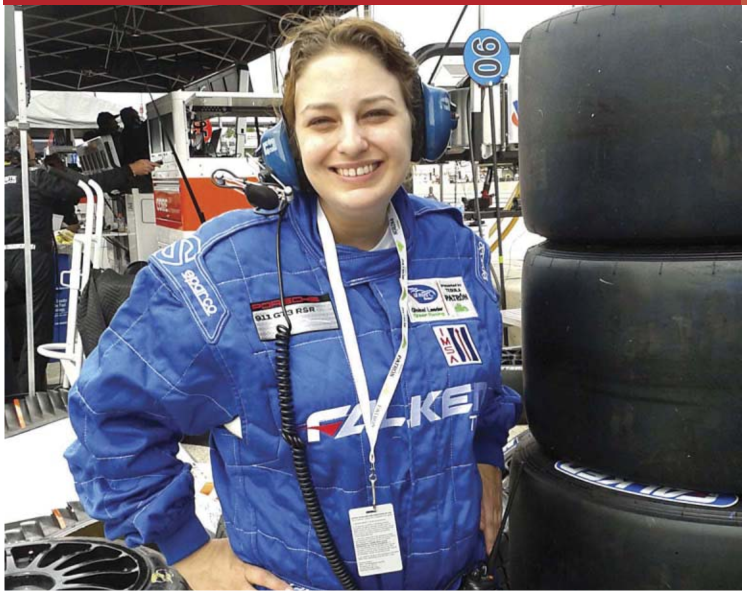

A Day at the Races

When a race car going more than 200 kilometers per hour crashes, spectators generally shudder. But journalist Alaina G. Levine's emotions were more mixed when she learned that Team Falken Tire's Porsche had spun into the fence during the final minutes of a 4-hour race held at Road America in Elkhart Lake, Wis. She was at this American Le Mans series race to interview Rick Mahurin, the team's electronics wizard, for his profile in this issue.

The crash showed him jumping "into superengineer mode," says Levine [above], who immediately saw the opportunity the crash presented, once she and others were assured that the driver had walked away unscathed. "I couldn't believe I had the good fortune to be there when this happened," she says. "It was, of course, disappointing to be part of the team that crashed, but the event really showcased Rick's talent."

Levine watched as the racing engineer scrambled to figure out how a tire could have blown without giving some advance warning in the telemetry he'd been monitoring. You don't get such intimate glimpses into someone's work very often–the opportunity to see him or her tackling significant challenges in real time. Levine knew the fates were being kind to her, even if they weren't being so kind to Mahurin's team.

Levine spent two days at Elkhart Lake interviewing Mahurin and his colleagues and generally throwing herself into his fast-paced world of American Le Mans racing. What's it like reporting from the pit, where the sound of roaring engines is so deafening you need radio-equipped headphones just to communicate with the people around you and where fireproof suits are de rigueur? She answers in just two words: "Totally awesome." ■

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PHOTOGRAPH BY Prachi Patel

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Seungyoung Ahn, Nam Pyo Suh, and Dong-Ho Cho

The authors of "Charging Up the Road" [p. 44] all work at KAIST, the Korea Advanced Institute of Science and Technology. Ahn [left] is an assistant professor of electrical engineering; Suh [right], a mechanical engineer, is former president of KAIST; and Cho, an electrical engineer, is vice president. Their project to charge vehicles with roadway-embedded cables began with trams and trains; next come passenger cars. "We first tried our idea of charging electric vehicles wirelessly on a model car," says Ahn, "and now people at the lab can't stop playing with it."

Steve Hodges

The leader of the Sensors and Devices group at Microsoft Research Cambridge, in England, Hodges experiments with hardware for new kinds of human-computer interaction. He helped create the Gadgeteer platform for rapid prototyping, which he used in his quest to reinvent the alarm clock [p. 16]. The platform lets you "get up and running within minutes and iterate to a pretty polished device," says Hodges.

Susan Karlin

A frequent contributor to *IEEE Spectrum*, Los Angeles–based Karlin often looks at the impact of technology on the entertainment industry. In this issue, as part of our continuing series of profiles of notable start-ups, she shifts her focus to Tactus Technology, a company that's introducing a new haptic technology for touch screens [p. 19]. Its display with buttons that pop up on demand was a hit at this year's International Consumer Electronics Show.

Neil Savage

In "Path Found to Combined MRI and CT Scanner" [p. 13], Savage describes IEEE Fellow Ge Wang's research on interior tomography, which he first came across while reporting on how medical device firms were trying to reduce the X-ray dosage produced by their imagers. Savage, a longtime *Spectrum* contributor, says, "With the growing popularity of scanning, finding ways to limit radiation exposure is important."

Lawrence Ulrich

For *Spectrum*'s annual review of top tech cars [p. 30], Ulrich took to the roads of Italy and Morocco. But he says the all-electric Tesla Model S he test-drove in Chicago is technologically the most significant of the bunch. "It's hard writing about electrics," he says. "They have a different mix of strengths and weaknesses than we're used to. It's good that they're so quiet, but it can also be bad, both for the rev-hungry driver and for timorous pedestrians."

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When Innovating, Go Slow

Advances in technoscience take human ingenuity—and time

The tangled history of innovation reveals a peculiar lesson: Slow is often better than fast.

The current assumption is that innovation at its best hits like a hurricane. Austrian-American economist and political scientist Joseph Schumpeter, who first recognized the importance of innovation for economic growth, famously described innovation as coming in "gales," sweeping aside all that came before.

But whether it's biomedical, digital, or electromechanical, systems-level innovation requires human ingenuity, even wisdom. And the wise adaptation of advances in technoscience–in the design, engineering, and management of large knowledge-based systems that deliver energy, information, transportation, security, food, and health–takes time.

Rapid monumental shifts do occur, of course. Think of the speedy switch from wired phones to smartphones, or from TV to streaming video on the Internet, or the quick decline of snail mail, now replaced by a siege of e-mail, Twitter, and Facebook. But Schumpeter's gales of innovation often mask slower, deeper changes that are more important, although less obvious. Few monumental shifts render existing technologies obsolete right away, and the social impact of new technologies often takes decades to reveal itself.

In some industries, innovation simply has to be slower. Regulations and litigation aimed at preventing harmful outcomes from new medical therapies and health interventions invariably slow the pace of change in health care. Digital engineers often boast of rapid product releases and the need to "fail cheaply and quickly." But a badly designed laptop or search engine won't kill anybody. Makers of new drugs or medical implants, such as hips or pacemakers, are speed averse out of self-preservation.

Energy and transportation systems also change slowly, and not because the engineers and scientists who work on them are out of ideas. The prevalent carbon-based energy paradigm is so complex that seemingly small input substitutions can have enormous negative consequences. For example, biofuels could be used to power automobiles instead of gasoline. Yet when scaled across nations as large as the United States or China, the widespread adoption of biofuels would greatly increase the price of food, as well as the amount of land needed to grow it, erasing any environmental gains we might make from abandoning gasoline.

Entire systems rarely spring forth fully formed. Drones or robot-controlled aerial vehicles, for instance, seem to have emerged suddenly, with pundits, politicians, and ordinary citizens now wondering how their use will change not only the way war is waged but every aspect of our lives. Yet drones have a long historical tail. Hot-air balloon "drones" were used in the French Revolutionary Wars. The Wright brothers conceived of unmanned aircraft more than 100 years ago. Lawrence Sperry, who perfected the gyroscope, developed a mechanical autopilot in 1912. Electrical engineer Nikola Tesla described a fleet of unmanned aerial combat vehicles in 1915. Almost a century of development on many fronts went by before the drones everyone is now talking about "suddenly" appeared.

Slow innovation doesn't mean no innovation. What looks to some like an innovation drought may instead be a period of yet-to-be appreciated innovation already under way. Flashy, fast innovation may be sexy; it satisfies investors impatient for a big score in the short term. But for the people who use the technologies that innovation brings about, and for those who engineer them, slow is the way to go. –G. PASCAL ZACHARY

G. Pascal Zachary is a professor at Arizona State University's Consortium for Science, Policy & Outcomes.

NEWS

29 MODERATE-TO-STRONG SOLAR STORMS HAVE STRUCK SINCE 2009

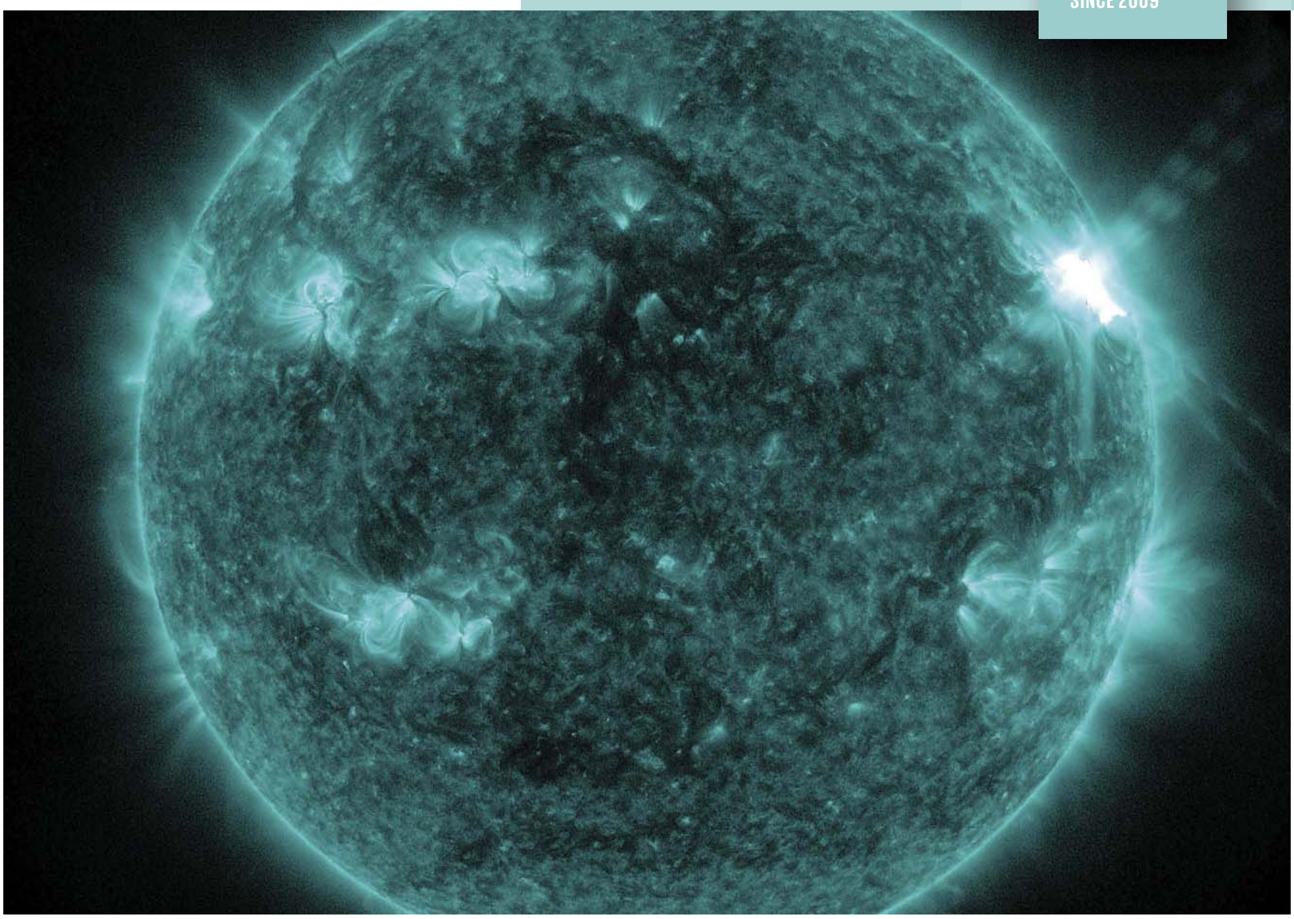


PHOTO: SOLAR DYNAMIC OBSERVATORY/NASA; INFOGRAPHIC SOURCE: NOAA, SPACE WEATHER PREDICTION CENTER

PROTECTING THE POWER GRID FROM SOLAR STORMS

New spacecraft will aid forecasts of space weather

STORM WATCH: A March 2012 solar flare looks impressive but caused no problems here on Earth.

IT CAN HAPPEN: Every so often the sun emits an explosive burst of charged particles that makes its way to Earth and, under just the right conditions, wreaks havoc on power grids. A powerful geomagnetic storm in March 1989 blacked out the entire province of Quebec, leaving millions of customers in the dark and damaging transformers as far south as New Jersey. Lately the question being debated in space weather circles is: Are we prepared for a repeat, or a storm 10 times worse—like the 1859 solar superstorm?

Thanks to two new satellites, we might be better prepared than ever. The Deep Space Climate Observatory, which will measure the solar wind at the Sun-Earth L1 Lagrange point, some 1.5 million kilometers from Earth, is set for launch next year. L1 is a gravitational sweet spot ideal for observing the sun because it's never shadowed by the moon or Earth. Also slated for 2014 is an experimental solar-sail mission dubbed Sunjammer, which will fly » more than a million kilometers closer to the sun than L1 and could become the basis for a space-weather early-warning system.

The Deep Space Climate Observatory (DSCOVR) began life 15 years ago, as an Earth-observing satellite called Triana that was championed by then vice president Al Gore. But the nearly complete satellite was grounded by politics and a change in administration. "So we just put it in a clean-room container, under nitrogen purge," says Adam Szabo of NASA's Goddard Space Flight Center, who is project scientist for DSCOVR.

It wasn't forgotten, though. The United States' National Oceanic and Atmospheric Administration (NOAA), which is in charge of issuing space weather forecasts, had long sought a dedicated satellite for such work but lacked the funding. Triana seemed like an inexpensive solution: It was already built, it had instruments on board for measuring solar wind, and the Air Force agreed to pay for the launch, aboard a SpaceX Falcon 9 rocket.

Last fall NASA engineers began refurbishing the satellite. "We completely took it apart," Szabo says. "Every bit was removed, every subsystem and component was checked." Most were okay, he says, but a couple of parts were suspect. "Good thing we didn't launch with those." This spring, they're reassembling the satellite, and then they'll subject it to a battery of testing and verification. The earliest possible launch date is November 2014, he says, but the satellite has to be ready a year before that. Once it is on orbit, NASA will turn it over to NOAA.

To keep costs in check, no new instruments are being added to DSCOVR, despite the change in its job description. The satellite already had a flux-gate magnetometer and a Faraday cup. The cup scoops up protons and measures the particles' velocity, temperature, and density. Meanwhile, the magnetometer determines the vector of the solar magnetic field.

Measurements from DSCOVR will be intercepted by ground stations and piped to NOAA's Space Weather Prediction Center in Boulder, Colo. There, automated software will process the data within seconds and turn them into "actionable information," Szabo says. "It cannot be more than 5 minutes between measurement on the spacecraft and when an operator in Boulder picks up the phone or sends out an e-mail warning. That's a tall order."

Also in the works is Sunjammer, being built by L'Garde, of Tustin, Calif., as a way to provide even earlier warnings. Named for the Arthur C. Clarke story of the same name, the spacecraft boasts a 0.1-hectare solar sail that's designed to let the craft fly toward the sun using the inherent pressure of photons, explains Doug Biesecker, an astrophysicist at the Space Weather Prediction Center. Among other things, researchers hope to learn whether the giant sail will interfere with solar wind measurements.

Space weather experts agree that such projects are absolutely necessary—and not enough. At present, several of the key spacecraft NOAA relies on have exceeded their operational lifetimes, including the Solar and Heliospheric Observatory and the Advanced Composition Explorer (ACE). DSCOVR will replace the 15-year-old ACE but won't expand much on its capabilities. And Sunjammer is only a demonstration; no follow-ons have been funded.

In a perfect world, direct observations of the sun would translate into detailed alerts describing what the magnetic field will look like when it reaches Earth, where and when the storm will strike, and which grid components will be at most risk. That information would give grid operators several days to prepare. Today's forecasts offer only about 30 to 45 minutes of lead time.

Space watchers will note that these spacecraft will launch well after the current solar cycle has peaked. But the next great geomagnetic event could happen at any time. "The size of a solar cycle does not determine the size of space weather storms, only the frequency," says Biesecker. "So you could have fewer storms but just as severe, or more so."

Right now, interest in this area is high, notes Rich Lordan of the Electric Power Research Institute, in Palo Alto, Calif., whose electric utility members fund about $2 million annually in geomagnetic storm research. "It tends to follow the solar cycle." The trick, he says, is to keep the momentum going. "Let's finish [the work], let's not stop—as a gift to the people who will be running things 11 years from now." —JEAN KUMAGAI

RESIDENTIAL SOLAR POWER HEADS TOWARD GRID PARITY

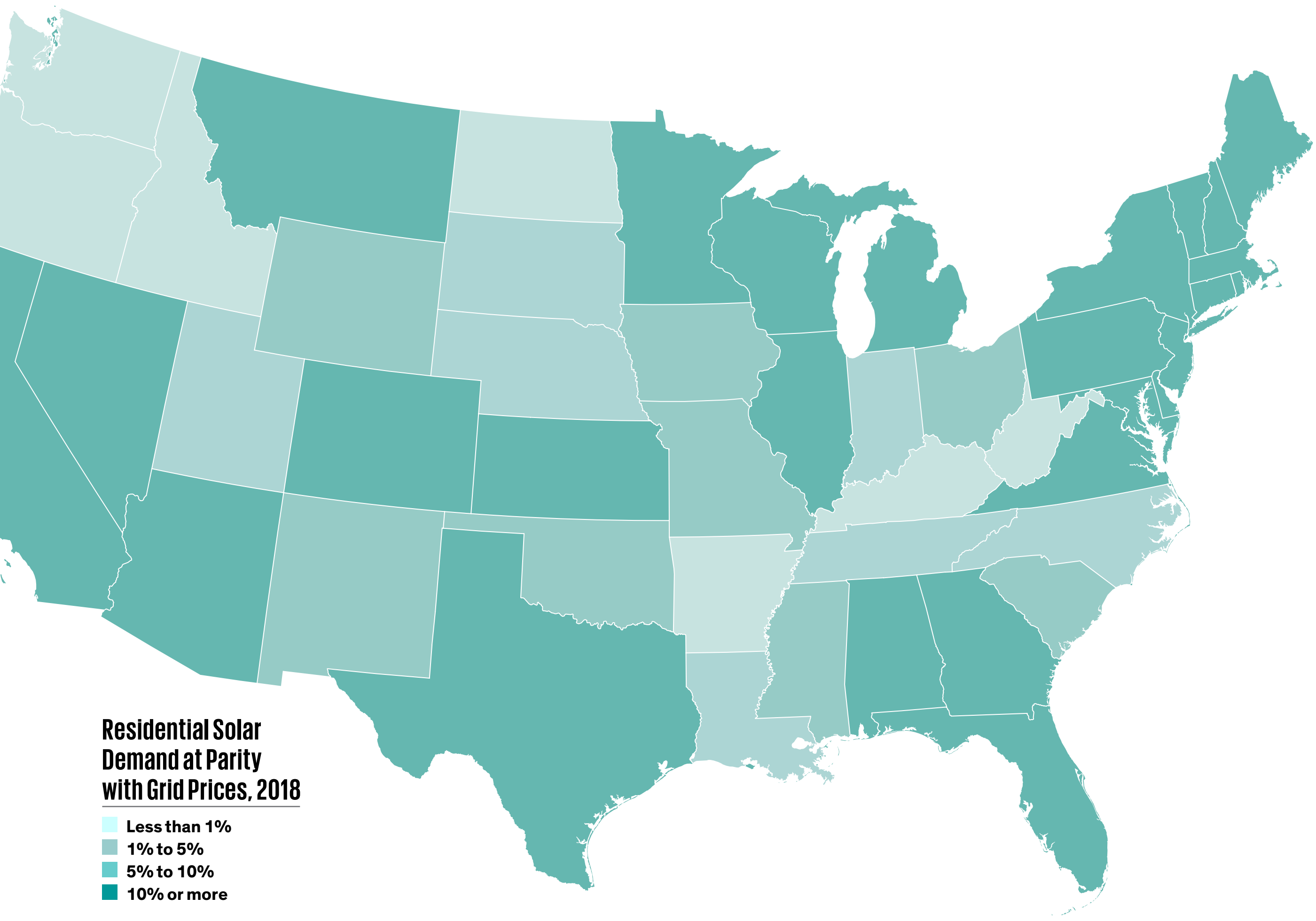
Some rooftop photovoltaics are already cost-effective

Photovoltaics are still, on average, a pricey, subsidy-dependent source of electricity. However, rooftop panels are beginning to beat the grid in a number of jurisdictions with high retail power rates—and their ranks are projected to swell over this decade. A growing number of economists say that rapidly shrinking costs have turned distributed solar generation into a disruptive technology that's set for runaway growth. In fact, they say, it could ultimately upend the power distribution market.

"We're completely unprepared for the opportunity that's going to present itself," says John Farrell, an economist and senior researcher at the Institute for Local Self-Reliance, a Minneapolis-based economic think tank.

Farrell got beyond the less-inspiring U.S. national average price of rooftop solar on homes and businesses by examining how it stacks up in each of 3100 electric utility rate zones across the country. He projected the per-kilowatt costs of generation from PV systems through 2022 by estimating the cost of installing and maintaining them over their 25-year lifetime and calculating the number of kilowatt-hours they are likely to generate under each zone's prevailing sunlight. Dividing cost by generation gave him what economists call the levelized cost of solar energy, which he compared to the local utility's retail power rates.

The results, presented since January as an online map, suggest that rooftop PV already delivers power more cheaply than the U.S. grid for more than 10 percent of residential demand in five states—California, Connecticut, Hawaii, New Hampshire, and New Jersey. By 2022, home panels are predicted to be the economic winner for at least 10 percent of residential demand in 49 states; the grid holds its edge only in the state of Washington, thanks to notoriously gray skies and cheap local hydro-



SOLAR SPREAD: Bright sun and high utility rates help rooftop solar energy compete with grid power. The map shows how much residential demand could be fulfilled by solar more cheaply than by the grid in 2018.

SOURCE: INSTITUTE FOR LOCAL SELF-RELIANCE

power. PV installed by businesses, meanwhile, will be competitive with at least 10 percent of total U.S. commercial power consumption in 2022.

Similar patterns for the United States emerge from academic reviews of PV power cost, such as one published this month by Stanford University researchers in the journal *Energy Policy*. And a global analysis by the Abu Dhabi-based International Renewable Energy Agency last year suggests that PV is at parity in Cyprus and parts of Italy and likely advancing fast.

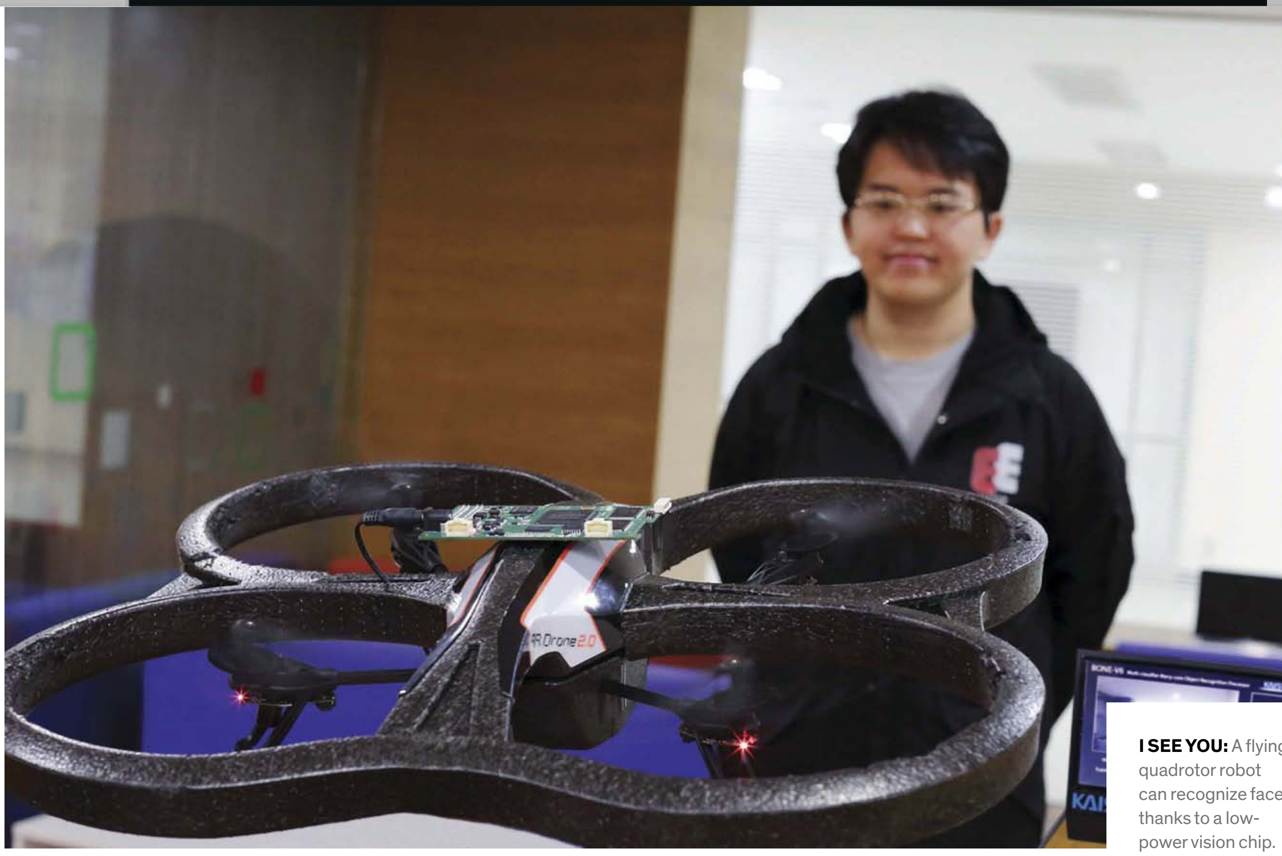
As with all economic projections, these studies rely on assumptions that are open to criticism. Farrell's assumptions, however, are relatively conservative. For instance, Farrell does not provide for any change in grid prices, which generally rise by about 2 percent per year. He also excludes federal and state subsidies for solar power installation. Add in the federal incentives and Farrell's 2022 nationwide parity moment for solar panels arrives in 2018, even in much of dreary Washington state.

The most controversial element in the new economic forecasts for solar is what drives its spread across Farrell's map as the years pass: the assumption that PV costs will continue to fall. Critics of solar energy attribute its plummeting prices to massive overproduction in China and to subsidy trimming in Europe. According to this argument, prices will rise as more producers go bankrupt (as Solyndra did famously in 2011 and others have since) and supply shrinks.

Stefan Reichelstein, faculty research director at Stanford's Steyer-Taylor Center for Energy Policy and Finance, however, says the evidence indicates otherwise. His study, in *Energy Policy*, evaluated the impact of the unusually large price drops in recent years—40 percent in 2011 alone. Replacing PV's recent dips with an extension of its historic price curve, which has been remarkably smooth for three decades, only increases the levelized cost of today's systems by 12 to 15 percent. This suggests that the real drivers of PV's price decline are technology and industrial efficiency, and there is no reason to believe they will hit a wall.

For their part, utilities are providing a strong signal that they recognize the distributed PV price trend, and the threat it represents to their business model: An increasing number of them are petitioning regulators for rate increases targeted specifically at solar users. —PETER FAIRLEY

NEWS



I SEE YOU: A flying quadrotor robot can recognize faces thanks to a low-power vision chip.

SEEING ON THE FLY

New systems could improve the vision of small flying robots

AERIAL ROBOTICS research has brought us flapping hummingbirds, seagulls, bumblebees, and dragonflies. But if these robots are to do anything more than bear a passing resemblance to their animal models, there is one thing they'll definitely need: better vision.

In February, at the International Solid-State Circuits Conference (ISSCC) in San Francisco, two teams presented new work aimed at building better-performing and lower-power vision systems that would help aerial robots navigate and aid them in identifying objects.

Dongsuk Jeon, a graduate student working with Zhengya Zhang and IEEE Fellows David Blaauw and Dennis Sylvester at the University of Michigan, in Ann Arbor, outlined an approach to drastically lower the power of the very first stage of any vision system—the feature extractor. That system uses an algorithm to draw out potentially important features like circles and squares from an overall image.

To navigate and to determine whether a scene looks familiar, a micro air vehicle needs to be able to use its entire field of view. But existing full-image feature-extraction algorithms are built to run on desktop computers and servers, not battery-powered platforms, Blaauw says. He adds that although there are some low-power feature-extraction algorithms, those tend to focus on very specific applications such as face recognition.

> Feature extraction is just one aspect of vision systems, but it can take up as much as 70 percent of the core on a vision chip.

The Michigan team's solution was to pare down a traditional feature-extraction algorithm, reengineering it to work well on a specialized image-processing accelerator and optimizing factors like the number of times a portion of an image is accessed for analysis. Image sections in traditional feature extraction may be analyzed a handful of times, because areas of interest often overlap. The new accelerator pushes data through only once, as if the data were on a conveyor belt. "We feed a little bit of the image through a bus, and all the little processors watch," Blaauw says. "When they see a part of the image they need, they grab it."

Jeon and his colleagues also incorporated a few hardware tricks to cut down on the power usage. One approach was to rework the shift registers that act as buffers for data that's in process. Typical shift registers are made up of cells with two latches—circuit components that contain about 10 transistors each. The team found a way to rework the registers so that their cells each contained only one latch. The resulting registers were just as fast, but because they

JUNYOUNG PARK

contained half as many latches they lost half as much power from leakage.

The team's accelerator, which consumes just 2.7 milliwatts of power, was made using a 28-nanometer manufacturing process. The core clocks at a very low 27 megahertz, which keeps the power consumption down; the clock on a typical vision system-on-a-chip works at more than 100 MHz. Although feature extraction is just one aspect of vision systems, Jeon says, it can take up as much as 70 percent of the area of the core on a vision chip.

Another approach, led by IEEE Fellow Hoi-Jun Yoo at the Korea Advanced Institute of Science and Technology (KAIST) in Daejeon, South Korea, is to attack the vision problem at the complete chip level. Yoo's team has built an SoC with 21 image-processing cores. The chip, which has been demonstrated on a toy car and on a four-propeller flying robot called a quadrotor, is capable of distinguishing faces and differentiating between objects and pictures of objects–for instance, a car and a billboard carrying the image of a car.

To save power, the chip can dynamically adjust the voltage and frequency as well as the number of cores used to process each video frame. The team also incorporated a mix of digital and analog circuitry to save power. All told, they were able to drop the power consumption of the chip down to 260 mW from typical object recognition SoC levels of more than 300 mW, says graduate student Junyoung Park, so that means more power can be set aside to keep a robot aloft.

Both the Michigan research and the KAIST work "have a similar design methodology in that they're taking vision algorithms developed over the last 20 years and squeezing them into new design architectures and circuit implementations," says Mike Polley, director of the Vision, Video, and Image Processing R&D Labs at Texas Instruments, in Dallas. He adds that we could see some of these approaches emerging in personal robots, cars, and other applications within five years. —RACHEL COURTLAND

NEWS

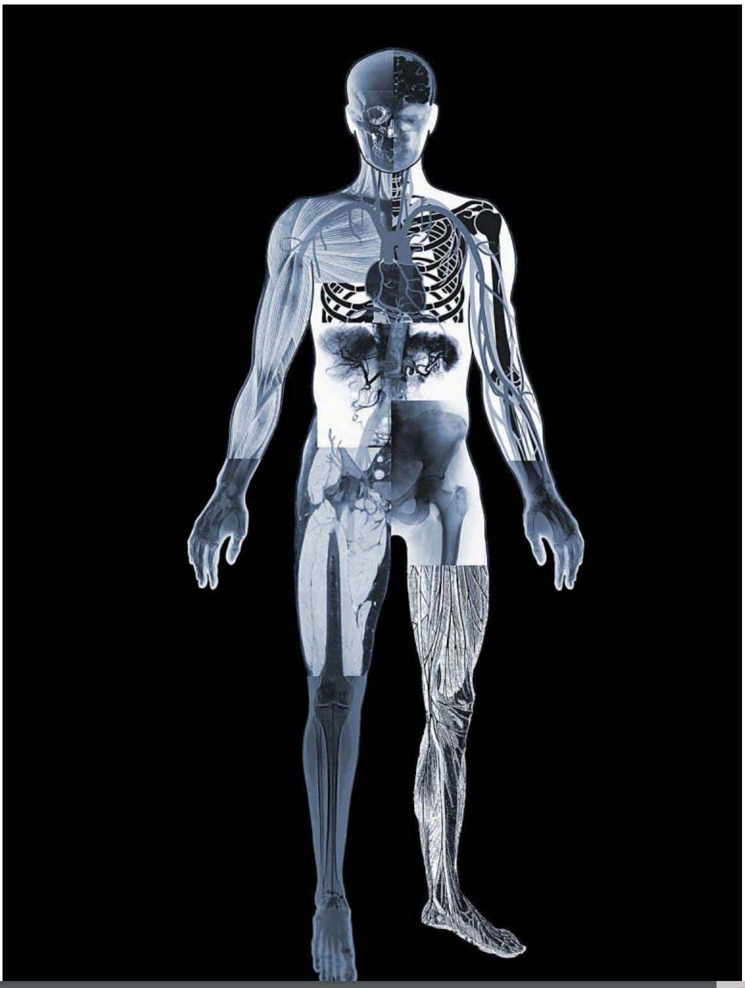
PATH FOUND TO COMBINED MRI AND CT SCANNER

Omni-tomography could add together the advantages of several medical imaging technologies

A TECHNOLOGY THAT better targets an X-ray imager's field of view could allow various medical imaging technologies to be integrated into one. This could produce sharper, real-time pictures from inside the human body, says a researcher who hopes to one day build such a unified imager.

Ge Wang, the director of Rensselaer Polytechnic Institute's Biomedical Imaging Center, in Troy, N.Y., calls his vision omni-tomography. Mixing and matching imaging techniques, such as computed tomography, magnetic resonance imaging, and single-photon emission computed tomography, could improve biomedical research and facilitate personalized medicine, says Wang, an IEEE Fellow.

To fit these imaging methods together, Wang and his collaborators have been developing a technology called interior tomography. In standard CT, X-rays pass through two-dimensional slices of the body, and then a computer



MEHAU KULYK/SCIENCE PHOTO LIBRARY/GETTY IMAGES

DATA BYTE

11.7 Strength of the magnetic field in teslas, in what will be the most powerful full-body MRI in the world when installed later this year near Paris.

processes the data to build up a picture. If the scanner is trying to image the aorta, for instance, it will X-ray a whole section of the chest, including the points where the body ends and the open air begins. That boundary provides the image-building algorithm with defined edges and the background information it needs to operate. But interior tomography focuses only on structures inside the body, which reduces the patient's radiation exposure. "If you're only interested in the heart, why bother to cover your whole chest with X-rays?" says Wang.

Narrowing the view, however, eliminates the usual reference points needed to create an image conventionally. Interior tomography relies on a different set of hints. The new technique uses information about how substances within the body (such as blood) and air pockets alter X-rays to provide the algorithm with a base for reconstructing the image. It can even use old X-ray images of the same patient to help out.

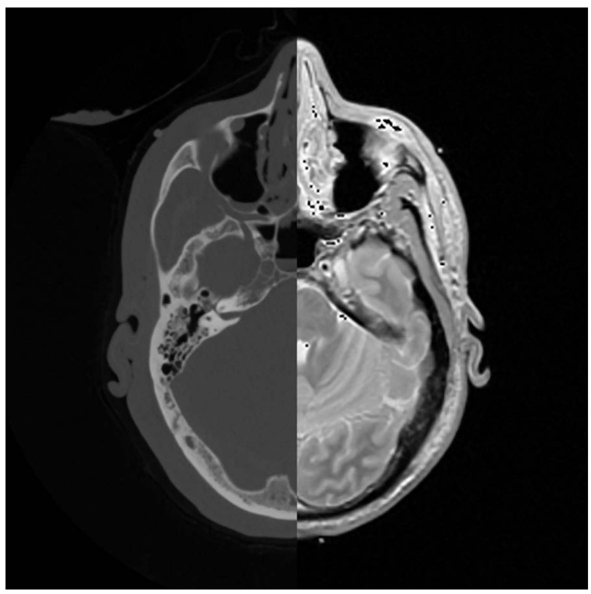
Focusing on a specific region has advantages, particularly with patients too big for conventional scanners. "If an object is wider than the X-ray beam width, classic theory says you cannot do an accurate reconstruction," says Wang. That's not a concern with interior tomography, he says.

What's more, Wang's team has shown that this concept can be generalized for use in imaging methods other than CT scanning, including MRI. And that could lead to a true fusion of major medical imaging techniques. In part that's because the technique allows the use of smaller X-ray detectors, which in turn makes it possible to fit more scanners into the same machine.

There are already systems that combine two imaging methods–PET and CT or SPECT and CT, for instance. But those systems usually apply different methods in sequence rather than simultaneously, making it harder to see biological processes in action. The combination of CT and MRI has never been attempted before, but Wang says it's possible now.

In fact, he and his collaborators in Australia, China, and the United States recently came up with a top-level engineering design for a CT-MRI scanner. They hope to present their design in June at the International Meeting on Fully Three-Dimensional Image Reconstruction in Radiology and Nuclear Medicine, in California. Applying interior tomography to MRI imaging allows the use of a weaker magnetic field, which is one way the design compensates for the incompatibility between powerful magnets in the MRI and rotating metal parts in the CT scanner.

Wang's team does not yet have the funding to build a combination CT-MRI scanner, but putting the two technologies together could prove useful. MRI gives high contrast and allows doctors to measure functional and even molecular changes; CT provides greater structural detail. Together, they might allow doctors to get a superior picture of processes in action, such as changes during a heart attack, or serve as a guide to a surgical procedure. The technology would be ideal for imaging vulnerable plaques, suggests Michael Vannier, one of Wang's collaborators and a radiology professor at the University of Chicago. Vulnerable plaques are buildups on artery walls that are particularly unstable and prone to causing heart attack or stroke. A combination of structural, functional, and molecular information is needed to tell just how dangerous the plaque may be. "In the long run, we think putting many imaging modes together will give you more information," Wang says.



SEEING BOTH SIDES: A CT scanner's X-rays [left side] provide good structural detail; MRI images [right] are good for seeing functional flaws. Omni-tomography could combine the two technologies in the same machine.

Interior tomography "is certainly an interesting concept that takes the interest in combining modalities to the 'ultimate' level of a single device," says Simon Cherry, director of the Center for Molecular and Genomic Imaging at the University of California, Davis. While omni-tomography is technically feasible, Cherry wonders whether it will make sense from a clinical and economic perspective. "There are some that say too many of our health-care dollars are spent on imaging, especially in the pursuit of defensive medicine. This will be an expensive machine," he says. "These are the issues that may well determine whether this approach is successful." —NEIL SAVAGE

IMAGES: HAO GAO & GE WANG; DATA BYTE SOURCE: NEUROSPIN

NEWS

RESOURCES

FACEBOOK STORES 100 PETABYTES OF DIGITAL PHOTOS AND VIDEO, EQUIVALENT TO A STACK OF BLU-RAY DISCS 2.8 TIMES THE HEIGHT OF MOUNT EVEREST.
SOURCES: FACEBOOK, BLU-RAY DISC ASSOCIATION

PLUSTEK

SAVING PHOTO SLIDES

RESCUE YOUR PHOTO-GRAPHS FROM THE ATTIC

RESOURCES_TOOLS

If you're old enough to have been called a "shutterbug," you've probably got a bunch of slides or film somewhere that you've fantasized about digitizing. Well, a new scanner system, flawed though it is, may be what you're looking for. ● Film scanning is recovering from a market implosion several years ago, when big players Canon, Minolta, and Nikon all either got out of the business or cut back their offerings. That left fewer than a dozen companies competing in the market for 35-mm film scanners. One of the most interesting of this group is Plustek Technology, whose new model, the OpticFilm 8200i Ai, offers impressive value. ● Available now in stores for about US $430, it can scan at 7200 dots per inch—high enough to show the grain in a photograph, no matter how fine-grain the film is. Its image-sensing component is a charge-coupled-device combined with an LED light source. Like all film scanners, the Plustek is equally adept at scanning negatives and slides. ● But good hardware is useless without good software. It's a big challenge for a scanner, because the software has to control so many variables, including spatial and color resolution, output format, and many optimization and correction parameters. The Plustek comes bundled with software called SilverFast, which is available for Microsoft Windows and Apple's OS X. ● SilverFast has an intuitive user interface. It enabled me to control the key factors of a scan with few false starts and with minimal use of the thin and mediocre reference booklet that comes with the software. Unfortunately, however, I also encountered a significant bug. Every time I tried to make a scan with the highest color depth—64-bit—the software crashed. This instability surprised me, because the software is now on version 8. (I was running it on my powerful iMac computer.) ● The Plustek scanner can perform several different kinds of scans, but they boil down to two basic types. One is an "archival" scan, which strives ▸

to capture every detail and aspect of the slide as faithfully as possible. Needless to say, this type of scan generates a huge file and takes a more than a few minutes to complete. The other type allows you to manipulate the image as it's being scanned and stored, for example to lighten or darken it, crop it, alter the contrast, compress it, hide its scratches, or change its color balance. However, I prefer to make an archival scan and then tweak it with Apple's Aperture, the photo-management software I'm most comfortable with.

Alas, the archival scans were consistently underexposed. The scanner uses a multiple-exposure scheme, in which the image is exposed and scanned twice. A bright exposure wrings detail out of the dark and shadowy parts of the image, and a dimmer exposure makes the most of the brightly lit areas. The SilverFast software then combines the two exposures into a single picture with high dynamic range, which in theory captures good detail in both bright and dark regions of the image. In practice, scan after scan was too dark.

The archival scans also take lots of time and disk space. To make an archival scan at 7200 dpi, and with 48-bit color depth, took 6 minutes and 40 seconds. The resulting TIFF image file occupied 383.1 megabytes.

Should the software problems get fixed, the Plustek OpticFilm 8200i Ai would be a tremendous bargain in a shrinking market that could really use one. But as things stand, I can recommend the unit only with a couple of caveats. For those who really want to archive slides, don't want to spend four figures, and won't settle for less than perfection, the wait isn't over. Your move, Plustek.

—GLENN ZORPETTE

Read an extended version of this review online.

TIME FOR GADGETEER

MICROSOFT'S SYSTEM FOR PROTOTYPING MAKES BUILDING YOUR OWN DEVICES EASY

STEVE HODGES

WE LIVE IN A HIGH-TECH WORLD, SURROUNDED BY NEW gadgets like smartphones and Internet TVs, along with other consumer products that were unheard of a decade or two ago. It's not surprising that we often overlook more established electronic devices. Take, for example, the humble alarm clock. Despite digital convergence, many of us still like a dedicated device that lets us know what time it is if we wake in the night and summons us to action in the morning. Sadly, alarm clocks appear to have fallen behind our other home electronics in their sophistication. So I decided to build a better one. ● For this I used Microsoft .NET Gadgeteer, a platform I helped develop as part of my day job in the Sensors and Devices group at Microsoft Research Cambridge, in the United Kingdom. Our work includes the SenseCam used at the heart of Gordon Bell's MyLifeBits project [see "Total Recall," *IEEE Spectrum*, November 2005]. As one of the few groups at Microsoft Research that creates new hardware, we designed Gadgeteer as a rapid prototyping system for our own needs. But we saw so much interest from others that we released it to the general public as an open-source platform in 2011. Several manufacturers now supply Gadgeteer

hardware that works in conjunction with free-to-download software.

So what extra features could anyone possibly want from an alarm clock? For starters, I've always found the typical controls frustrating. And the practically Jurassic seven-segment LCD or LED numeral display ubiquitous today could be much improved.

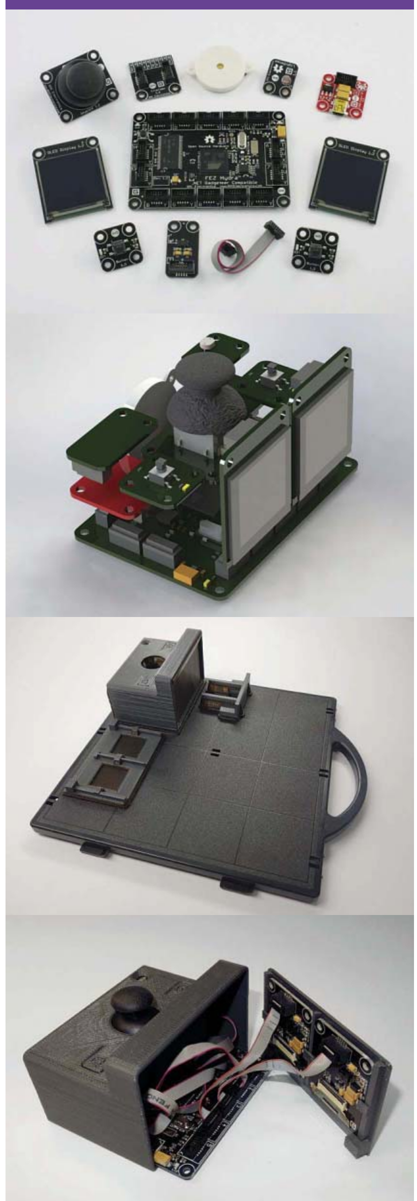
Gadgeteer is founded on a solderless approach that lets you build a device easily—and quickly rebuild it if it doesn't work quite how you imagined. You can readily connect hardware modules with various capabilities, such as a camera or an accelerometer, with pluggable cables. This gives a lot of freedom in designing both the functionality and the form factor of the hardware. About a hundred different Gadgeteer modules are sold online.

I began this project by selecting a thumb-joystick module and a couple of button modules for the controls. In my design, holding down one button selects the clock time and the other selects the alarm time. Pushing the joystick left and right sets the minutes; up and down sets the hours.

When it came to the display, my wife finds the dim glow that LCDs emit annoying at night, even when they are displaying black, so I chose two 128- by 128-pixel OLED screen modules, which don't have the glow problem. This allowed me to replace the blocky digits of yesteryear with bitmaps of hand-drawn numbers. I used a light-sensor module to control how bright the display is and added an accelerometer to silence the alarm with a simple shake of the clock. With Gadgeteer it's also relatively easy to build your own modules; I did just this to make the actual alarm noises by using a cheap piezoelectric sounder connected to an extension module.

For the brains of the alarm clock, I connected all these modules to a Gadgeteer mainboard—in this case a Fez Hydra from GHI Electronics, powered by a 240-megahertz ARM9 processor. Like all Gadgeteer mainboards, this runs the .NET Micro Framework and can be programmed over USB using a free version of Microsoft Visual Studio running on a host computer. The Hydra costs about US $80, while the module prices range from $5 for a button to $29 for an OLED display.

PLUG AND PLAY



Gadgeteer modules [top] provide the hardware functions required for a DIY alarm clock. A CAD software package [screen shot, second from top] was used to design an enclosure, which was printed [second from bottom] using a 3-D printer. The modules were then fitted and connected [bottom].

FROM TOP: STUART TAYLOR; STEVE HODGES; NIC VILLAR; STEVE HODGES

You can write the code that runs on Gadgeteer devices in either C# or Visual Basic. Unusually for a microcontroller system, Gadgeteer is built around an object-oriented and event-based methodology. This means that each physical hardware module is represented in code by a corresponding software object that exposes relevant methods, properties, and events. For example, when a button is pressed, a software event is automatically generated, which in turn triggers a block of code called an event handler to run. This is in contrast to the typical approach of having to program a controller to continually check the button to see if it's been pressed, or writing a traditional interrupt handling routine. Similarly, the accelerometer triggers an event handler to silence the alarm when it detects a shake. The alarm clock display is controlled via a software-only timer object that generates an event once every second.

Finally, if my new alarm clock is to be accepted alongside all the other consumer electronics in my bedroom, it must have a decent case. Handily, there are 3-D models of most Gadgeteer modules available at http://gadgeteer.codeplex.com. You can import these into computer-aided design software such as Solidworks or Autodesk's free-to-use 123D, and then arrange them in virtual space to match the physical hardware. Then you can design the enclosure around them in the CAD software and send the result to a 3-D printer or laser cutter. I used the Dimension Elite 3D Printer we have in our lab, but services like Shapeways or Ponoko can create and mail you an enclosure within a few days.

Now that I have the basic version of my clock working, I'm already thinking of making more upgrades. For example, I'd like to try using the accelerometer as an alternative way to set the time. A ZigBee module would let me display the outside temperature reading from a wireless thermometer. More ambitiously, I could use a Wi-Fi module to connect the clock to my home network and have the clock synchronize with calendar events, perhaps even wish me a happy birthday. Or maybe I'll just prowl around my house looking for other electronic devices to bring into the 21st century. —STEVE HODGES

RESOURCES_CAREERS

MOTOR SPORT MACGYVER

RICK MAHURIN APPLIES HIS TECHNICAL WIZARDRY TO AUTO RACING

LAST AUGUST, A SLEEK BLUE-AND-GREEN PORSCHE SPED at more than 200 kilometers per hour along the Road America racetrack in Elkhart Lake, Wis. The US $650 000 car, a 911 GT3 RSR, was just minutes from its final pit stop when it went careening off the course because of a blown tire. The race was over for Team Falken Tire, but the fun was just beginning for its data-acquisition engineer, Rick Mahurin, who had been monitoring the race via telemetry. ● Oddly, the car's extensive sensor network gave Mahurin no warning of the blowout. Although disappointed that the car's data stream couldn't prevent the crash, Mahurin looked forward to reengineering the wheel-sensor system to better detect incipient failures ● At age 49, Mahurin, who has spent half his life in racing, thrives on high velocities. "When everything starts to speed up, I get in my element," he says. "It's when things are slow that I'm uncomfortable." ● Modern race cars are stuffed with hundreds of sensors, measuring such parameters as tire pressure, engine speed, and steering-wheel angle. As cars fly by, Mahurin sits in the pit and concentrates on three computer screens. If he notices measurements creeping outside their normal ranges, he alerts the crew chief.

A history of clever tech fixes has burnished Mahurin's reputation. For example, he found a fresh solution to an old problem—determining how much fuel a car has when it rolls in for a pit stop. Race cars use rubber bladders to hold fuel, making it impossible to gauge fuel level conventionally. Mahurin rigged the car with scales that could measure the weight of the remaining gasoline, so that the pit crew knows exactly how much fuel they need to put in.

A large part of Mahurin's job is making fixes as economically as possible. "We don't have an unlimited budget," he says. "I'm able to sort of MacGyver things." At one race, the team discovered that some of its equipment had gotten lost in transit. "We didn't have any antennas," Mahurin recalls with a laugh. "So I made them out of a coat hanger."

As a youngster Mahurin went to drag races. Later, he enrolled at Purdue University, in Indiana, starting out in computer technology before switching to mechanical engineering. A classmate was working for a shop that built engines for cars racing in the Indianapolis 500. "All the parts were shiny and really intricate," he says. "I realized this is the place I needed to be." He was soon working in racing shops, helping to design and build components while he continued his engineering studies in the evenings.

If you want to work in racing, Mahurin says, get to know some teams. Although the industry is fickle, with teams going in and out of business every year, talented people can find stable careers: The key is being a "known quantity," he insists. "Once you get a reputation for being somebody who can get it done, that's pretty much all you need." Mahurin himself has been employed by nine different racing teams and companies, including his current stint with Walker Racing, which Falken Tire Corp. has contracted to run its race-car endeavors.

As much as he loves the excitement of the track, Mahurin also enjoys tinkering between races. After the crash at Road America, he spent a week scrutinizing the car's sensors to be sure they weren't damaged. He installed new electronics for collecting and processing raw readings as well as junction boxes designed to simplify the wiring of the car's onboard video system. The following week, at a track in Baltimore, his brain raced in parallel with the Porsche as he watched it win.

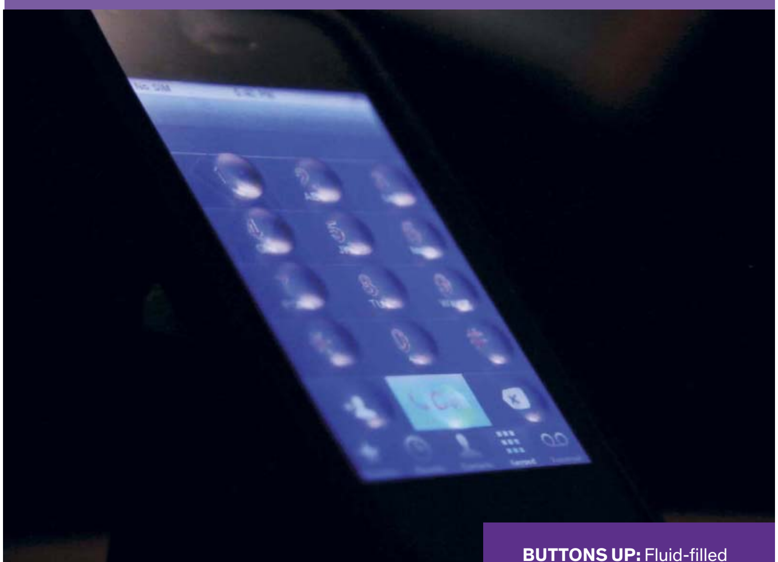
Silicon and software, as much as rubber and steel, made that victory possible, Mahurin notes proudly. "When the systems that you have in place enable you to do your job, and it all comes out the way it's supposed to, it's a joy." —ALAINA G. LEVINE

Read an extended version of this profile online.

PHOTOGRAPH BY David Yellen

RESOURCES_START-UPS

TACTUS TECHNOLOGY
THIS CES DARLING ADDS TACTILE FEEDBACK TO VIRTUAL KEYBOARDS



BUTTONS UP: Fluid-filled cells provide tactile feedback for touch-screen keyboards.

TACTUS TECHNOLOGY

IN THE SIX YEARS SINCE APPLE introduced the iPhone, with its stylus-free multitouch display, touch screens have become the preferred interface for mobile devices. Market demand for touch screens shows no signs of slowing. Last year's worldwide revenues of US $16 billion are anticipated to jump to $31.9 billion in 2018, according to market research firm DisplaySearch.

However, without the tactile feedback provided by buttons, it can be easy to lose a sense of where you are on the display or of data you have entered. Or you can accidentally enter data by just resting a finger on the screen.

Fremont, Calif., start-up Tactus Technology is gunning to be the first to market a solution to this problem: Its display features fluid-filled buttons that pop up on demand, and the surface reverts to a flat screen when the buttons are no longer needed. The firm—which has raised $7.5 million so far—was founded in 2008 by longtime friends CEO Craig Ciesla, a fiber optics specialist, and CTO Micah Yairi, who had previously worked on drug delivery systems. Last year, its technology won Display Week's I-Zone Best Prototype Display Award, CEA's Eureka Park Challenge Grand Prize, and *PC Magazine*'s Technical Excellence Award. It was also chosen as one of the best products at the 2013 International Consumer Electronics Show (CES) by CNNMoney, *Wired*, and Engadget.

"To our knowledge, we're the only one doing this," says Nate Saal, Tactus's vice president of business development. (A few years ago, Carnegie Mellon University Ph.D. student Chris Harrison developed a similar technology that used air instead of fluid, but it does not appear to have been commercialized.)

Tactus's system is intended to be incorporated during manufacturing, forming the touch display's outer layers. A see-through elastic polymer lies on top of a transparent layer containing microchannels filled with oil. These microchannels have holes located at each button location, connecting the channels to the polymer layer. To make buttons appear, the oil is squeezed through the channels, and thus through the holes, pushing up the elastic layer. The touch screen below senses the user's fingers pressing the buttons. When typing is complete, the liquid is sucked out and the buttons go down.

One of the major challenges, says Yairi, was making the buttons and channels almost completely transparent. The solution was to use an oil whose index of refraction matches the surrounding material.

"It's definitely an innovative solution from a technology standpoint," says Tony Costa, a Forrester Research analyst covering emerging consumer technologies. "It's a tough technology problem to solve, and they've done a good job. I think it will find a home in niche markets, but I don't see it as a broad mass-market product."

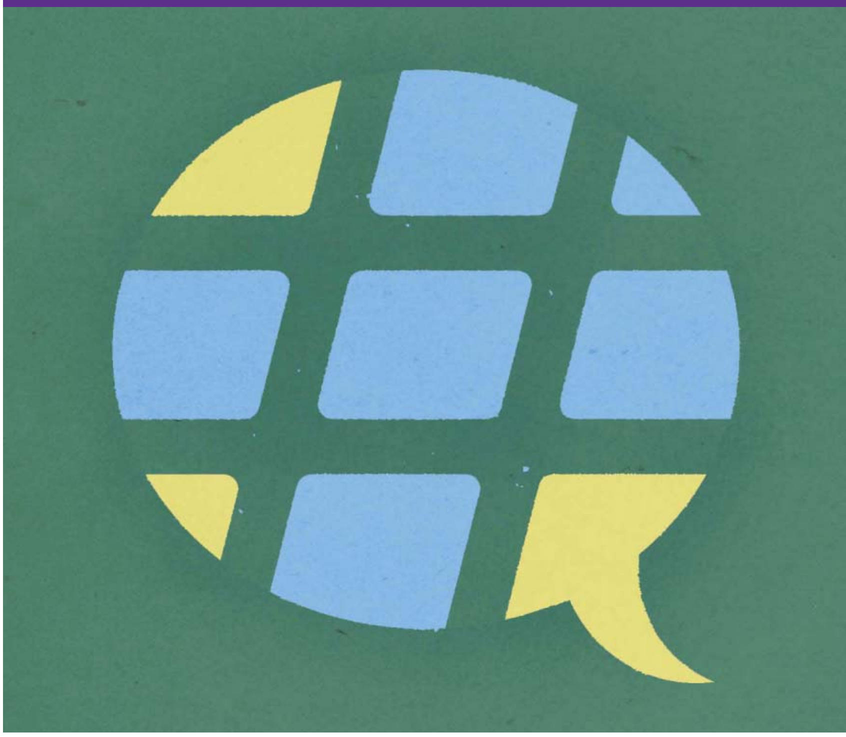
Costa suggests that increased tactile response is better suited to remote controls, ATMs, industrial equipment, medical equipment (for personnel wearing gloves), seniors with declining physical sensitivity, companies like BlackBerry (whose users favor smartphones with physical keyboards), and consumers who use tablets as laptops.

"It's a generational thing. For people who have grown up with Android phones and iPhones, it's fairly normal for them to type on a touch screen," says Costa. "Doing both appeals to people accustomed to keyboards, but that's becoming a smaller part of the market over time."

During the next year, Tactus plans another financing round to scale to production level. It has partnered with Taiwan-based TPK Holding Co.'s Touch Revolution division, a leading touch-screen manufacturer, and plans to ship to undisclosed device makers by the end of this year. Launch dates for those devices are still undisclosed. But, says Ciesla, "market interest was answered by our incredible reception at CES."

—SUSAN KARLIN

Founded: 2008; Headquarters: Fremont, Calif.; Founders: Craig Ciesla and Micah Yairi. Employees: Undisclosed; Funding: US $7.5 million; http://www.tactustechnology.com



HASHTAG, YOU'RE IT

This was the year when the hashtag became a ubiquitous phenomenon in online talk. In the Twittersphere and elsewhere, hashtags have created instant social trends, spreading bite-sized viral messages on topics ranging from politics to pop culture. **—Ben Zimmer, chair of the New Words Committee of the American Dialect Society**

BACK ON 23 AUGUST 2007, Google interface designer and BarCamp cofounder Chris Messina posed a fateful question on Twitter: How do you feel, he asked, "about using # (pound) for groups. As in #barcamp [msg]?" It was the first use of a **hashtag**, which is a term preceded by the hash (or pound or number) sign [#] that serves to group similar tweets. People talking about, say, the World Economic Forum, might include #Davos or #WEF in their tweets. Searching Twitter for a hashtag returns all the recent tweets that include it. • In the nearly six years since this humble beginning, hashtags have come a long way. Twitterers have applied it in all sorts of ways. For example, the **rhetorical hashtag** is used to clarify, comment on (often ironically or sarcastically), or shade the meaning of a tweet. For example, if someone complains about some relatively unimportant issue, but then adds the hashtag #FirstWorldProblem (meaning a complaint that could be experienced only by a privileged person living in a wealthy country), then we know the person gets how trivial it is. • The **hashtag game** is a pastime that uses special hashtags called, appropriately, **gametags** to create Twitter-based contests. For example, in early 2012 an unknown **hashtag gamer** came up with #FiveWordTEDTalks, which asked people to create TED Talks consisting of just five words. (My favorite: "Computers! Wow, right? Computers! Geez.") A popular variation on this theme is to play with existing cultural artifacts. In the hashtag game #MedicalFilms, for example, Twitter came up with film titles like *Harry Potter and the Sorcerer's Kidney Stone* and *12 Angry Patients*. Some of these are so popular they end up on Twitter's Trending chart and so become the **hashtag du jour**.

On a more serious note, **hashtag activism** uses hashtags to promote projects or causes (particularly when it requires no other action from people, making it a form of *slacktivism*, which was discussed in this column in June 2011). So you personally might not be able to do much about, say, the gun laws in the United States, but you can certainly add the hashtag #GunControlNow—or its antithesis, #SecondAmendment—to your tweets.

No human endeavor is beyond the reach of marketers these days, so no one is surprised by **hashtag marketing,** which promotes a company, product, or brand with a hashtag. McDonald's recently tried to burnish its brand by creating a hashtag (#McDStories) with which people could share heartwarming times spent in McDonald's restaurants around the world. More subversively, marketers will attempt to promote a company-friendly hashtag in ways that appear to come from ordinary citizens, simulating a **grassroots hashtag** (or **grasstag**).

The corollary to the above is, of course, that no human endeavor is beyond snark these days, so lots of people enjoy hijacking a corporation's marketing hashtag to mock the company, a practice known as **hashjacking** or **tagjacking.** A corporation's Twitter hashtag, when used to bash the company's products, becomes a **bashtag.** The #McDStories hashtag was only a few hours old before it found its way into tweets that described McDonald's-related horrors.

Given all this, and given that hashtags are now often seen "in the wild" (on other social networks, such as Facebook, and even off-line on T-shirts), it's no wonder that *hashtag* won out as the American Dialect Society's Word of the Year for 2012, beating out solid contenders such as *fiscal cliff, Gangnam style,* and *YOLO (You Only Live Once)*. So whether you look at it technically, culturally, or linguistically, the hashtag is, as Charlie Sheen might say, #winning. ■

ILLUSTRATION BY Jesse Lefkowitz

WHERE THE LASERS MEET: **Technicians work inside the target chamber of the National Ignition Facility.**

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STAR POWER

The National Ignition Facility houses the world's most powerful laser. Is it enough to ignite a fusion revolution?

BY RACHEL COURTLAND

When the world's most powerful laser zaps a target, it's eerily silent. If you're close enough to know the exact moment the system fires, chances are you're standing in a darkened control room, watching a silent countdown. The only hint that something has occurred is a timer that hits zero and immediately starts counting up again. But hidden from view is an experiment of staggering proportions and precision: 192 laser beams streaming through halls that span the length of football fields, steadily gaining in strength before they finally converge within millimeters of one another, triggering the implosion of a peppercorn-size capsule.

Here at the Lawrence Livermore National Laboratory, a U.S. national security laboratory tucked amid vineyards and undulating grassy hills about an hour east of San Francisco, the lasers of the National Ignition Facility (NIF) have already created the intense pressures and temperatures needed to get atoms of hydrogen to fuse. But NIF is trying to achieve a far more challenging goal, one that countless researchers have sought for decades. NIF's aim is not just fusion but fusion's equivalent of a chain reaction, a self-sustaining "burn" capable of producing more energy than is needed to get the process started in the first place.

So far, this feat—called ignition—has been accomplished only in a relatively crude way, inside nuclear weapons, where the energy released by splitting atoms is used to trigger a fusion explosion. NIF is designed to bring about ignition on a smaller scale. Doing so could help stave off the need for future nuclear weapons tests, supporters say, and could inch humanity closer to the long-held dream of nearly limitless and clean commercial fusion power.

But it hasn't all been smooth going: NIF's past year has been a peculiar mix of triumph and defeat. In July, after years of construction delays and daunting technical hurdles, and a little more than three years after the facility's formal dedication, NIF's engineers finally pushed the lasers to their design specifications. In a handful of microseconds, they showed they could deliver more than 1.8 megajoules of energy in a laser shot that packs some 500 terawatts of power, about 1000 times as much power as the United States consumes, on average, at any given moment.

When NIF was conceived, that was thought to be more than enough power and energy to achieve ignition. But it didn't happen. A 30 September deadline for ignition established by NIF's funding agency, the U.S. Department of Energy's National Nuclear Security Administration (NNSA), came and went. Now, expectations have been significantly scaled back. In a report sent to the U.S. Congress in December, the NNSA said that it is "too early to assess whether or not ignition can be achieved at the National Ignition Facility."

CENTRAL COMMAND: Laser shots at the National Ignition Facility are coordinated from a single room, modeled after NASA's mission control room in Houston.

DAVID BUTOW/REDUX

Critics of NIF seized on this uncertain conclusion as further evidence that the facility—which saw its construction costs triple from initial estimates to US $3.5 billion—should never have been built at all. They allege that NIF isn't likely to achieve ignition and that even if it manages to do so, the feat is unlikely to be of much benefit to society. NIF officials reply that the facility is performing cutting-edge science for the benefit of all humankind and that it has already made a significant contribution to our understand-

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Looking In

This window offers a view into the center of the National Ignition Facility's target chamber. Visible here is the final optics damage inspection system.

ing of the basic physics of nuclear weapons. When NIF achieves ignition, they say, it will mark a turning point in the 60-year-old quest to harness fusion for peaceful purposes. But as the delays pile up, sorting out what exactly to believe might be almost as difficult as the quest itself.

HARNESSING THE PROCESS that powers the stars has been the intent of many different kinds of projects over the years. But the two most well-funded approaches have been magnetic confinement and inertial confinement. The leading example of the magnetic approach is the ITER project, a $20 billion experiment currently under construction in southern France, which will use magnetic fields to confine and heat a plasma. NIF's inertial approach, on the other hand, contains its plasma by blasting away the outer layer of a target in order to force the remaining matter inward, in the process creating the temperatures and pressures needed for fusion.

ITER, which is currently slated to come on line in 2020, is unambiguous and highly specific about its intent: to advance fusion as an energy source—a high-yield and largely pollutant-free replacement for fossil fuels. NIF has also embraced that energy goal, but within a larger, less specific context that is heavy on defense-related research.

During a lunchtime interview at Livermore in August, NIF's director, Edward Moses, outlined a vision for a power plant based on NIF's approach to fusion. NIF currently can fire a laser at a precisely placed stationary target every 12 hours or so. A power plant could potentially be economical if it could be designed to fire much faster—"pop, pop, pop," Moses says, gesturing over bits of a sandwich—so that it can zap a stream of dropping fuel pellets at a rate of 15 per second.

Nothing like this scheme has ever been accomplished, even on an experimental basis. Nevertheless, it is eminently feasible, Moses insists. All that's needed is for NIF to light the way with the initial demonstration of ignition. "People are going to think about the future differently once this works," Moses says.

If NIF does blaze a trail toward commercial fusion power generation, it will be all the more noteworthy because NIF's primary purpose is not power generation but rather national defense. The idea for the facility emerged in the early 1990s, around the same time that the United States was preparing to put a halt to the underground testing of nuclear weapons. The test moratorium, initially signed by President George H.W. Bush in 1992, put limits on the country's ability to assess weapons performance. This left the United States with a stockpile of roughly 14 000 nuclear warheads. Some two-thirds of those weapons have since been decommissioned, but the others must be maintained and periodically assessed.

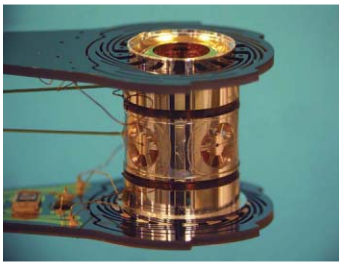
To do this, the U.S. Department of Energy devised a program called science-based stockpile stewardship, to better understand the physics of nuclear weapons and to assess the effects of aging on the nuclear arsenal. NIF is the flagship facility in this program, which includes materials and fusion experiments at two other

On Target
This long position arm is used to center the target inside the target chamber. It also serves as a reference for alignment of the laser beams.

national laboratories, as well as substantial computational clout. This year, Livermore's new 16-petaflops Sequoia supercomputer, which held the title of world's fastest for a few months in 2012, is to be commissioned for classified weapons-simulation work. The output of this research program is supposed to support the NNSA's "life extension" effort, which focuses on examining and upgrading aging nuclear weapons to ensure that they are still safe and can be detonated reliably for another 30 years or so.

In the absence of nuclear testing, experiments like NIF are important, says Marvin Adams, a professor of nuclear engineering at Texas A&M and chair of the weapons science review committee at Los Alamos National Laboratory, in New Mexico. Weapon materials degrade, and safety and environmental regulations introduced over the past four or five decades have made it extraordinarily difficult to reconstitute the ability to make weapons components exactly as they were made during the Cold War, Adams says.

What's more, there are still a number of outstanding questions when it comes to performance. During the years of underground testing, engineers saw anomalies and surprises in test results; in some cases, Adams says, devices that were supposed to undergo a critical stage of fusion didn't, and others didn't release as much energy as simulations predicted they would. "We know our codes are not perfect," Adams says. NIF officials say that improving those codes with results from the facility's experiments could help stockpile caretakers understand the impact of potential changes.



HOLLOW HOHLRAUM: NIF's ignition experiments use metallic cases, or hohlraums, like this one to hold the material to be fused. The case is destroyed in the process.

But how exactly will those results help maintain the stockpile? Not surprisingly, scientists and officials affiliated closely with NIF generally decline to give much detail, citing the need to keep the information confidential for national security reasons. "Once we get specific, we get classified," Adams says.

There are two ways ignition comes into play in a modern nuclear weapon. The first stage of a warhead, the primary, consists of a hollow sphere made of plutonium or uranium that is filled with a gas made of two isotopes of hydrogen—deuterium and tritium. When high explosives placed around the sphere are triggered, the blast compresses and compacts the shell, setting off a fission chain reaction of splitting atoms. The process sends neutrons and heat into the gas-filled center of the compacting shell, triggering fusion of the gas. This fusion step, called boost, releases neutrons that stream out through the shell, splitting yet more atoms and releasing enough heat in the form of X-rays to set off the warhead's "secondary." This stage consists of a ball made of a solid mix of lightweight atoms—typically lithium and hydrogen—that then fuse to create most of the energy released when a warhead explodes.

NIF officials say the facility will help study

LAWRENCE LIVERMORE NATIONAL LABORATORY (2) and maintain aging weapons in two key ways: first, by improving simulations of the early stages of ignition and the physics of a self-propagating fusion burn; and second, by performing "nonignition" tests on materials, such as plutonium, that are currently present in weapons as well as materials that could be used to replace aging components. These tests are used to examine how well such materials transport X-rays, resist deformation, and behave under pressures and temperatures that can be achieved only at NIF.

But NIF's relationship to stockpile stewardship is far from uncontroversial. Some physicists say the link between warhead performance and the fusion of tiny, delicate targets is tenuous at best. The energy scales in a nuclear weapon are far different from those NIF can produce, and the physical processes that set off the boost phase are too different to draw a helpful link, says physicist Richard Garwin, a member of the government advisory group JASON and one of the designers of the first hydrogen bomb. "[NIF] has no relevance at all to primaries. It doesn't do a good job of mimicking secondaries," Garwin says in an interview. "It validates the codes in regions that are not relevant to nuclear weapons."

Robert Hirsch, an energy consultant who directed fusion energy research at the Atomic Energy Commission in the 1970s, when laser-fusion research began ramping up, is impressed by the facility but also has reservations. "[NIF is] a great instrument, and they've done tremendous things to get it to operate," he says. "Is the cost benefit worth it? That's a different question." He has some doubts about NIF's defense justifications. "The answers seem a little bit fluffy in my opinion," Hirsch asserts. "It's not clear how well those arguments would stand up to serious scrutiny."

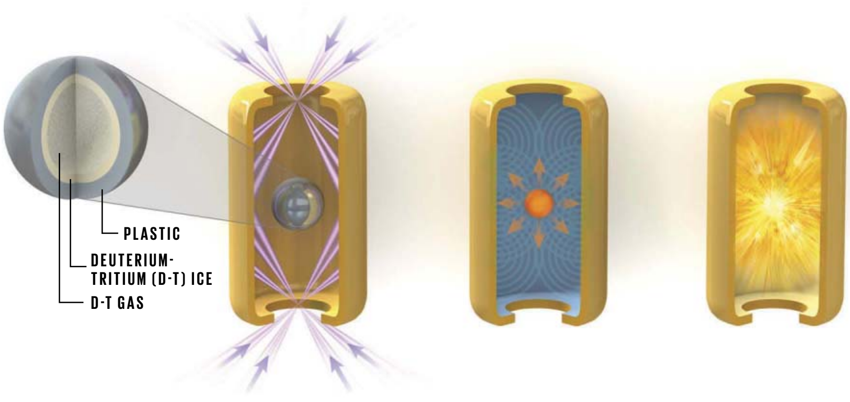
NIF's defenders point out that the facility has already made a significant contribution to stockpile stewardship (more on that below). They add that the facility performs another vital role by attracting talented people to the weapons community. Without interesting experiments to work on, Hirsch says, maintaining the stockpile would be a dull, largely "janitorial" job. But whether the facility can make any headway on some of the most interesting physics questions—and get humanity closer to fusion power—will all come down to whether NIF can live up to its middle name.

THE PATH to ignition starts in a single room containing three small, ytterbium-doped optical fibers. These compact fiber lasers generate the pulses that will ultimately bombard the target capsule, but only after being amplified 4000 trillion times in successive stages as they pass through a massive series of optics. The main amplifiers are a series of 3072 individual meter-length glass slabs, stored high up in two long laser halls. These slabs are doped with neodymium atoms that can be excited by flash lamps just before a beam arrives, triggering the emission of yet more photons.

The optics must be carefully protected from dust. At NIF's light levels, even minor atomic flaws in the glass can absorb enough energy to melt and fracture the surrounding material. These fractures can focus the light in unintended ways, creating intense hot spots in a beam that can create even more damage as the light propagates down the line of optics.

To minimize this sort of destruction, the amplifiers and other laser sections can be accessed only through a portable clean room or a specialized box that can form a tight seal. The laboratory has also built a small industry around damage mitigation. After a laser shot, engineers can use a telescope in the target chamber to look back through every line of optics for damage; each defect gets a number. They then use blue LEDs to program liquid-crystal-based screens through which beams pass before amplification. These screens can be made to have any arbitrary pattern of transparent and opaque areas, creating dark spots in a beam in order to circumvent damaged areas down the line. When too many defects accumulate, the engineers remove the damaged component and send it to another building, where the surface is re-treated and carbon dioxide lasers are used to etch out damage, leaving behind optically neutral conical pits. Nowadays, up to 40 pieces of optics, mostly the target-chamber focus lenses and debris shields—protective screens between the target chamber and the rest of the optical line—are pulled and sent away to be refurbished each week.

NIF conducts several different types of experiments with these lasers. Some are focused on compressing or irradiating particular targets related to the nuclear stockpile or else pure materi-



The Path to Ignition

1. Laser light enters both ends of the hohlraum, striking and heating the inner surface.

2. The resulting X-rays propagate toward the center, where they heat and blast away the outer part of the target.

3. In reaction, the remainder of the target accelerates inward and begins to fuse.

ILLUSTRATION BY Emily Cooper

All Clean

Pink glass slabs like this one are used to amplify laser pulses. The structure shown here allows for minimal handling by human hands.

als like diamond for basic materials science. Others are tailored toward illuminating a particular bit of physics related to ignition. When the facility conducts an ignition shot, however, it uses a very specific kind of pellet: a 2-millimeter-wide hollow sphere (so far, most have been plastic) filled with a gas consisting of equal parts deuterium and tritium. These two neutron-heavy isotopes of hydrogen are the easiest to fuse. The pellet is cooled to 18 degrees above absolute zero, which causes the hydrogen closest to the outside of the sphere to form a roughly 100-micrometer layer of ice that is some 10 times as dense as the gaseous fuel at the center.

There are no lasers in a nuclear weapon, so NIF is pursuing ignition using an alternate approach, called indirect drive. Instead of converging directly onto the fuel pellet, NIF's lasers shine through two holes at either end of a hollow container, called a hohlraum. The lasers heat the walls of this hohlraum, creating X-rays that in turn irradiate a pellet, which sits suspended between two trampoline-like skins made of ultrathin polymer.

Post your comments online at http://spectrum.ieee.org/ignition0413

When X-rays hit the pellet, they blast away the plastic coating on the outside of the fuel, and the resulting implosion drives the deuterium and tritium inward, creating a ball of fuel that's about 1/40 000 its original volume. If this reaction happens fast enough, a hot, high-pressure spot forms in the center of the fuel. This spot can reach 100 million kelvins, more than six times the temperature at the center of the sun. Deuterium and tritium atoms fuse to create streams of neutrons and helium atoms. As these helium atoms zoom outward, they collide with the frozen fuel, which is already compressed to a density some 100 times that of lead. If conditions are right, the heat from these colliding particles will be enough to fuse many more atoms and create ignition, sending more energy out than was put into the hohlraum to begin with.

So far, however, Mother Nature has not played along. Some four years before NIF started experiments, NIF's scientists, and the project's managers at the NNSA, expected that ignition might be achievable in just a few years. "Back in 2005, there were some concerns due to budget issues," says Christopher Deeney, director of the NNSA's Office of Inertial Confinement Fusion. So the NNSA came up with a plan, called the National Ignition Campaign, at the request of Congress, that proposed a series of milestones for the facility. The NNSA's plan called for ignition by the end of the campaign this past September. But that timetable was based on early simulations of the lasers and the target, and it now seems to have been overly optimistic (Deeney calls it "success oriented"). The problem, he says, is that "the codes do not seem to be reproducing exactly what we're seeing in experiments."

The discrepancy between the two is basically a mystery at this point. The simulations have to account for a lot of complex physics, of course. And it doesn't take much for an ignition shot to miss its mark. If the deuterium-tritium ice layer is imploded too quickly or too unevenly, it can crack and cause high-temperature material to mix with the colder fuel, driving down the pressure of the reaction and dampening the fusion. And the most infinitesimal asymmetry in the X-rays can cause the fuel to squash less like a sphere and more like a pancake, which reduces how much of the kinetic energy of the fuel ultimately translates into compression.

"This isn't something nature wants to give you easily," says John Lindl. I'm meeting with NIF's chief scientist late one afternoon in December, a few months after the National Ignition Campaign's close. One of the key difficulties, he explains, comes down to laser interactions with gases and material sloughed off the inside of the hohlraum. "The problem is, this isn't a vacuum–there's a lot of stuff in here," he says, sketching out the cylinder on my pad. The lasers "pass through one another, and they pass through one another in the presence of a high-temperature, pretty high density gas." Density fluctuations in the gas can cause beams to diffract or pass energy from one to another. The NIF team's current theory is that, in part due to all of these interactions, the lasers are not hitting their marks exactly, creating an asymmetry in the X-rays.

Lindl says that the team had been getting "tantalizing hints" from fairly crude X-ray images down the length of the hohlraum that the implosion might not be symmetric. In October, they set up an X-ray camera in the target chamber capable of taking 2-D snapshots during compression, including | CONTINUED ON PAGE 52

LAWRENCE LIVERMORE NATIONAL LABORATORY

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CST STUDIO SUITE 2013
Make the Connection...

TOP 10 TECH CARS: *SLENDERIZED*

THIS YEAR'S CARS DO MORE WITH LESS WEIGHT

BY LAWRENCE ULRICH

IT'S OFFICIAL: GUZZLING GAS IS OUT OF STYLE. IN AUGUST, the Obama administration finalized U.S. standards that will nearly double the average fuel mileage of cars and trucks by 2025. The rule slices auto greenhouse emissions in half, virtually matching the European Union's proposed 2020 target of 95 grams of carbon dioxide per kilometer driven. • But how are we going to get there? Electric cars and plug-in hybrids have so far fizzled with rank-and-file consumers, due to a familiar trio of obstacles: high cost, short pure-electric driving ranges, and long recharging times. And yet among this year's Top 10 Tech Cars, one model did stake a bold new claim for the viability of electric cars: the groundbreaking Tesla Model S. • Even so, *IEEE Spectrum*'s 10-car convoy proves that there are other ways to wring more miles from a liter of fuel. A trend of "lightweighting" has begun sweeping the global industry, as automakers seek to reverse decades of bloat caused by modern crash protections and deluxe amenities. The brainpower of cars is also rapidly expanding, with a Japanese sport sedan taking a small but important step toward automated cars: It has a full "drive-by-wire" steering system that backs up the driver. Turning the stereotypes on their heads, there's a whopper of a British SUV and a bite-size Chevrolet. What they have in common is a high ratio of driving pleasure to fuel burned.

PRICE: Not available
POWER PLANT: Four-cylinder turbo, 224 kW (300 hp)

NISSAN *DELTAWING*

It flies through the air with the greatest of ease

AFTER A QUIXOTIC four-year quest by engineer Ben Bowlby, the DeltaWing has proved to be the most radical, rule-breaking race car in decades. Starting with a tiny, 1.6-liter turbocharged four-cylinder with 224 kilowatts (300 horsepower), the arrow-shaped DeltaWing has half the power of rival racers. But with half the weight, aerodynamic drag, and fuel consumption, this 475-kilogram (1047-pound) missile can still reach 315 kilometers per hour (196 miles per hour).

Too bad IndyCar and other sanctioning bodies rejected the design, in part because of skepticism over its ballistic shape: With insanely skinny, 100-millimeter-wide tires packed together up front, the DeltaWing looked like a land-speed candidate that might barrel-roll at the first hint of a curve. In fact, despite an unusually heavy 72.5 percent rear-weight bias and no external wings, the DeltaWing's downforce-producing body proved its ability to pull nearly 4 *g*'s through corners. Backed by Nissan, Michelin, and others, the DeltaWing was finally granted a special exhibition slot, called Garage 56, at the 24 Hours of Le Mans in France in June. Six hours into the race, this underdog—and crowd favorite—was booted into the wall by one of the front-running Toyotas. In the pits, Bowlby wondered aloud if his baby might ever get another chance.

It did, and just four months later, at Road Atlanta, in the American Le Mans Series' season-ending Petit Le Mans. In practice, the risk-loving driver Gunnar Jeannette was again struck on track, sending the car dramatically airborne. Yet despite starting dead last in the 42-car field, Jeannette passed eight cars on the first lap in the hastily rebuilt Nissan. Because the Nissan's feathery weight saved wear on its tires, it skipped multiple tire changes, allowing it to place as high as third before finishing fifth overall. It was a remarkable showing for a rookie with barely more power than a typical V-6 sedan. The DeltaWing also consumed just 55 percent of the fuel of a Nissan-powered V-8 competitor that the team benchmarked during the event.

The DeltaWing's future remains in doubt, despite plans to run some ALMS events this year. Yet like the winged Chaparral racers of the '60s, the DeltaWing has proved doubters wrong.

SKINNY BUT ROBUST: The DeltaWing's body slips through the air easily yet directs enough aerodynamic downforce to stay firmly planted on the pavement.

ALL PHOTOS PROVIDED BY MANUFACTURERS

INFINITI Q50

Today, drive by wire; tomorrow, drive by robot

MANY CARS ALREADY apply their own brakes and adjust their own throttles to avoid collisions. Now Infiniti has taken the next big leap toward cars that can drive themselves, with steer by wire. The Infiniti Q50 changes direction without any mechanical connection between the steering wheel and the front wheels. The system uses sensors to measure how much the driver has turned the steering wheel, then calculates the desired amount of vehicle turn and relays the appropriate commands to a pair of actuators. The actuators are what actually pivot the car's steering rack, which in turn angles the front wheels.

For easier low-speed maneuvers or high-speed stability, sensors can instantly vary power-steering assist and even the degree to which the steering wheel must be turned to effect a certain change in the car's direction. With no physical connection, Infiniti says, the system can better filter out unwanted noise, such as rough-road vibration and impacts, sending only desirable feedback to the driver. It can account for any tendency for tires to wander off-line and thus requires fewer steering corrections from the driver.

Nissan says the system can be faster and feel more responsive because it doesn't waste time and energy on mechanical connections. The lane-departure system gains as well: Instead of using brake interventions to crudely adjust the car's attitude, the windshield-mounted camera can alert the steering to keep the car centered.

When fly-by-wire airplanes were introduced, some pilots worried that a haywire computer might run away with things, HAL 9000–style. So the industry included redundant systems. Nissan has done the same thing by providing three independent electronic controllers. There's even a physical backup: Under a failure, a clutch engages to restore a driver's mechanical control. But in the future, Infiniti acknowledges, those training wheels will likely come off, because eliminating the bulky steering linkage entirely would save weight and complexity.

STEERING: Steer by wire **PRICE (ESTIMATED):** US $39 000 **POWER PLANT:** 3.7-L V-6, 245 kW (328 hp); gas-electric hybrid option

FERRARI F12 BERLINETTA

Again, we get unmatched speed from the master of same

CREATING THE "FASTEST FERRARI IN HISTORY" means you have to one-up automotive legends like the Enzo, so you're in for some serious engineering. • Yet with its unprecedented formula of wind-cheating brute force, the F12 Berlinetta is indeed the quickest production car to emerge from Ferrari's redbrick factory in Maranello: A top speed of 340 kilometers per hour (211 miles per hour) and an acceleration of 0 to 100 km/h (0 to 62 mph) in 3.1 seconds. Now all you need is US $316 000, and perhaps some esoteric trim demands to verify those claims. Bespoke denim interior, anyone? • For all its potency, this Ferrari's greatest reward may be its pleasant nature, the way it lets even amateurs in on a real-life video game—minus the crash-and-burn endings. The dusty hills surrounding the company's northern Italian home are an apt playground. By the second century B.C.E., the Via Aemilia was one of four great roads leading to Rome. And in today's Emilia-Romagna,

PRICE: US $316 000 **POWER PLANT:** 544-kW (730-hp) V-12 **FUEL ECONOMY:** Don't ask. But if you must, it's estimated at 15.7 L/100 km (15 mpg)

the narrow, crumbling roads suggest that the Roman army was the last to make repairs.

Yet with its array of Formula One technology, including a seven-speed F1 paddle-shift transmission, F1-Trac stability system, and road-taming rear differential, the Ferrari F12 still hews to the GT mantra. This successor to the lovely 599 comfortably accommodates runaway drives, runway-model legs, and custom Poltrona Frau luggage.

The nerve center is the *manettino*, the tiny crimson lever on the steering wheel that adjusts the parameters of multiple systems–engine, throttle, transmission, and stability and traction–for either a burbling cruise or a bellowing trip around a racetrack.

That beautiful music comes courtesy of the most powerful naturally aspirated V-12 in human history: a 544-kW (730-hp) 8700-revolution-per-minute masterwork that serenades the cabin via intake resonance tubes. Yet myriad reductions in internal friction–along with an engine stop-start system, a clutch-activated smart alternator that charges only when needed, and a multispark ignition system–reduce fuel consumption and emissions by 30 percent versus that of the 599.

The F12's space frame and body shell employ 12 types of aluminum alloys, providing 20 percent more torsional rigidity than its predecessor yet weighing 70 kilograms (154 pounds) less. And though Ferraris are known for their alluring bodies, this is the first one with cleavage. The innovative Aero Bridge directs air through two plunging valleys in the hood, along door channels and into the "blown" spoilers surrounding the rear wheel wells. The air interacts with their wake to reduce air pressure and drag.

The Aero Bridge, spoilers, and a vortex-producing flat underbody–so artfully formed that it's worth crawling under for a peek–create the most aerodynamic Ferrari ever, producing 123 kg of downforce at 200 km/h. That's a massive 76 percent more stick-to-the-pavement force than exerted by the 599.

A revised magnetic suspension joins an F1-based carbon ceramic braking system with Active Brake Cooling, via brake-duct vanes that open only when brake temperatures require it. Those brakes halt the F12 from a speed of 200 km/h in a remarkable 131 meters. The F12 has also recorded history's fastest lap on the company's venerable Fiorano test track, completing the circuit in 1 minute 23 seconds–a second or two faster than the Enzo ever did.

But forget the track times and technical wizardry. This is the most responsive, fun-to-drive Ferrari F12 in history, and that's saying a lot. Its computer controls are constantly churning, striving to maximally apply that Zeus-like power to the pavement. Yet the mortal behind the wheel is hardly aware of it.

In my hands, the Ferrari subdued some of the nastiest, goat-trammeled two-laners in northern Italy, and with the serene assurance of the local maître d's. The F12 hurtles and howls, pivots and drifts, stops from supernatural speeds. Excessive enthusiasm summons flashing stability control alerts at various levels of electronic oversight, depending on your bravery with the manettino switch. But those throttle, transmission, or brake interventions, nearly as instantaneous as those of an F1 car, never interrupt the torrent of sensation and performance. Squeeze the gas, flick the quicksilver steering, and the Ferrari responds like a genie nestled within a fragrant, leather-lined designer bottle.

Considering the F12's price and Fabergé-like elusiveness, there's only one problem: Even a genie probably couldn't get you one. ■

RAM 1500

This pickup's as powerful as it looks, but it's frugal with fuel

ONCE UNREPENTANT GUZZLERS, as comfortable as a bus-stop bench, full-size pickup trucks are cleaning up their act. And beneath its big-rig exterior, the new Ram is the cleanest of the bunch.

It starts with the optional Pentastar V-6 engine, a cylinder count that used to get you laughed out of the truck stop. But with a respectable 227 kilowatts (305 horsepower) from 3.6 liters, the V-6 has plenty of grunt for work or play. And the highway fuel economy is a best-in-class 9.4 liters per 100 kilometers (25 miles per gallon). Economy is aided by an eight-speed automatic transmission, until recently the province of six-figure luxury sedans—or a $470 000 Rolls-Royce Phantom Drophead Coupe, one of several models that share the Ram's ZF eight-speed.

PRICE: US $23 585 **POWER PLANT:** 3.6-L Pentastar V-6, 227 kW (305 hp) **FUEL ECONOMY:** 9.4 L/100 km (25 mpg)

On the road, a class-unique air suspension makes the Ram feel nearly as supple as a family car, with five adjustable ride heights. The pickup automatically lowers its body and closes front grille shutters to slice the wind on the highway. A press of the key fob makes the Ram squat like a low rider to help occupants clamber aboard.

Inside, Chrysler's newfound attention to design and materials shines through. And riders as diverse as work-site foremen and bored children can appreciate the Ram's available Sprint data connection, including Wi-Fi hot-spot capability.

FORD FUSION *ENERGI*

Ford hits the magic mark: 100 miles per gallon

TOYOTA MAY HAVE been synonymous with hybrids, but Ford is finding strength in numbers—fuel economy numbers. With more style and sport than the Toyota Camry Hybrid, the Fusion Hybrid also beats the Camry in fuel efficiency, with 5 liters per 100 kilometers (47 miles per gallon) in both city and highway. Now a plug-in version, the Fusion Energi, becomes the first production midsize car to hit the magic 100-mpg mark (2.4 L/100 km).

The United States' Environmental Protection Agency says the Fusion Energi returns the gasoline equivalent of 2.2 L/100 km (108 mpg) in city driving and 2.6 L/100 km (92 mpg) on the highway, for 100 mpg overall. That tops a pair of smaller rivals, the Chevy Volt and Toyota Prius plug-in, and even some pure electric cars, including the Tesla Model S.

For both the Fusion Hybrid and the Energi, a 2.0-liter four-cylinder seamlessly mates with an electric motor to produce a total of 140 kilowatts (188 horsepower). In the Hybrid, the electric motor spins up 159 newton meters (117 foot-pounds) of torque, and it's housed within an impressively light, compact, and seamless continuously variable transmission. That robust power unit can propel the Fusion Hybrid at up to 100 km/h (62 miles per hour) on electricity alone, a record for a conventional hybrid and 24 km/h higher than the previous model. For the plug-in Energi, Ford adds a 7.5 kilowatt-hour lithium-ion battery pack, which it says will deliver 34 km of all-electric range before the gas engine kicks in.

The best part is that both models drive beautifully, feeling more like conventional sedans than hybrids. But some fine print is involved: First, the Fusion Hybrid's mileage is notably fragile, falling to 5.9 L/100 km (40 mpg) or lower in less-than-ideal driving conditions. As for the Energi, it's expensive, at US $39 495 to start. That's $350 more than the Volt, but the smaller-batteried Ford is eligible for only a $3750 federal tax break, half that of the Volt. Still, Ford says the Energi can save the owner up to $6850 in fuel costs over five years, compared with the average new car.

PRICE: US $39 495 POWER PLANT: Plug-in hybrid of 2.0-L four-cylinder engine and electric motor, total power of 140 kW (188 hp) FUEL ECONOMY: 2.4 L/100 km (100 mpg)

PRICE: US $84 500
POWER PLANT: 5.0-L V-8
FUEL ECONOMY: 12 L/100 km (20 mpg)

LAND ROVER *RANGE ROVER*

It's lighter than it looks

THREE HUNDRED SIXTY KILOGRAMS. That's the weight of four or five men. That's how much ballast the new Range Rover has tossed out, illustrating the automotive trend toward lightweighting. Half that savings was realized in the new aluminum structure—a first for any SUV—which weighs a mere 292 kg (644 pounds), 23 kg less than the steel bones of a compact BMW 3-Series. This Rover now weighs as little as 2200 kg, equipped with a 280-kilowatt (375-horsepower), Jaguar-sourced 5.0-liter V-8. Step up to the 380-kW (510-hp) supercharged version and the slenderized Brit explodes off the line to break 97 kilometers per hour (60 miles per hour) in 5.1 seconds. That's faster than many sport sedans and nearly a second quicker than the outgoing model.

In tandem with a discreet eight-speed automatic transmission, the Rover's fuel economy has risen by nearly 15 percent, hitting 12 liters per 100 kilometers (20 miles per gallon).

And from rain-swept dunes along the coast of Morocco to the tangled streets of Marrakech, the Rover also showed me newfound agility to go with its magic-carpet ride and throne-like seats. An adaptive air suspension adjusts over five ride heights. The optional Dynamic Response system limits body lean, controlling the electrohydraulic roll bars independently at both axles. In the ridiculously posh cabin, riders find 12 centimeters (4.7 inches) more legroom in back and quieter surroundings than in a BMW 7-Series or Audi A8. And while many owners will limit off-roading to puddles at the neighborhood football pitch, the Rover will still vanquish terrain like William the Conqueror did at the Battle of Hastings.

Ascending Morocco's Atlas Mountains, our cliff-hung, red-clay road was cut off by the previous night's mudslide. Turn back? Forget it: Our Rover convoy climbed up boulder-strewn ridges and then down again to meet the road. A pop-up console button adjusts the Terrain Response 2 System through road-sensing settings including sand and rock crawl, mud and ruts, and grass, gravel, and snow.

Though the weight has gone down, the price certainly has not: The new Rover ranges from US $83 500 to $130 950. Yet thanks in part to that aluminum diet, the Range Rover has assured its continued, healthy reign among luxury SUVs. ■

TANQUAM EX UNGUE LEONEM: **"We know the lion by its claw." In this case, the cat is the famous carmaker, Jaguar, the claw is the wheel, and the leonine heart is a V-8 engine.**

CHEVROLET SPARK

Who needs dashboard buttons?

THE SPARK IS a brave experiment for Chevrolet: a funky city car, 5 centimeters (2 inches) shorter than a Mini Cooper, and ultra-affordable at US $12 995 to start. An electric version on sale later this year, expected to produce more than 540 newton meters (398 foot-pounds) of torque, will be General Motors' first production EV since the EV1 of the '90s.

But in technical terms, consider the Spark a 1000-kilogram box with a cool gizmo inside: Chevrolet MyLink. Instead of the pricey embedded hardware and software found in nearly every automobile, the Spark integrates all music, phone, navigation, and video through a smartphone and its apps. Those phones communicate with the Spark's simple 18-cm display screen, which is nearly devoid of hard buttons and needs no dashboard navigation systems or switches. Such gadgets are notorious cash cows for automakers, with consumers beginning to question why they should pay $1000 or more for optional navigation units that become obsolete faster than the cars themselves. By contrast, you can update the Spark's phone-based maps and systems by just downloading a new app, giving this bargain-priced Chevy a leg up over a six-figure Bentley. The Spark comes with Sirius XM satellite service and Pandora and Stitcher Smart Radio preloaded, with many more apps to come.

There are drawbacks. Smartphone antennas aren't as robust as car antennas, which means the Spark's apps, including route guidance, won't work in a barren desert. Providers are working to address these obstacles, perhaps by buffering or storing more critical data on board. But MyLink could shake up the traditional automotive order. This is a technology that may trickle up to top luxury cars.

PRICE: US $12 995 POWER PLANT: 1.2-L four-cylinder engine, 63 kW (84 hp) FUEL ECONOMY: 6.9 L/100 km (34 mpg)

MAZDA6

Japan unveils the diesel engine with the least compression

FOR AMERICANS, a diesel engine has specific connotations: a German car, a pickup, or a clunking Oldsmobile from the late 1970s. But with the Yanks finally embracing fuel-saving alternatives, the Mazda6 returns the hug as the first Japanese diesel car ever sold in America. Its 2.5-liter Skyactiv-G gasoline engine already boasts 6.2 liters per 100 kilometers (38 miles per gallon) on the highway. We figure the diesel version will boost highway mileage to roughly 5.3 L/100 km (44 mpg) when it reaches showrooms later this year.

Mazda bills its 2.2-liter beauty as the world's lowest compression diesel. The benefit? Diesels work by tightly compressing air and fuel inside a cylinder, raising temperatures to ignite fuel without needing a spark. But injecting fuel at the piston's "top dead center," or TDC—its tightest-packed, most power-efficient point—produces excess soot and smog-forming nitrogen oxides. Modern diesels trade off some of that efficiency by delaying combustion until the piston begins its descent. But Mazda's diesel reduces the compression ratio from 16.3:1 to 14:1, allowing injection at TDC and producing both a clean burn and a 20 percent improvement in fuel efficiency.

One reason for the improvement is the two-stage turbocharger system, which operates either a small or a large turbo to improve low-end torque and high-end horsepower. Another is the multihole piezo fuel injectors, which can deliver up to nine injections of fuel per combustion, ensuring cold-start capability—the main problem for any low-compression diesel, given the relatively low temperatures in the cylinders.

The Mazda trims fuel consumption by another 10 percent with i-Eloop, a novel regenerative braking system that stores energy in a highly efficient capacitor. As the Mazda decelerates, a variable voltage alternator charges up the capacitor in seconds. Throw in the hot looks and sporty handling and the 6 is set to combine economy and excitement like few other mainstream sedans.

PRICE: Undetermined FUEL ECONOMY (ESTIMATED): 4.4 L/100 km (53 mpg) POWER PLANT: 2.2-L diesel

TESLA MODEL S

The year's most significant car just happens to be electric

EVERY ELECTRIC VEHICLE comes freighted not only with batteries but with political baggage, too. Saviors to some, scapegoats to others, their honeymoon period is clearly over. • But in wintry Chicago, the Tesla Model S sedan managed over two fast-paced days to reaffirm the e-car's potential–not as a political chip but as a means of transport. And judged on its lofty technical achievement alone, the Tesla is the year's most significant automobile. • "We built a compelling car that just happens to be electric," says Ted Merendino, product planner for the California-based Tesla Motors. "And we think the Model S is the first alternative fuel vehicle that's done that." • The Tesla isn't the tiny, sluggish short-ranger that some people have come to expect EVs to be. With the largest of three available battery options, this swift, alluring sport sedan can cover an EPA-certified 265 miles (426 kilometers) on a charge, although Tesla claims 300 miles. In either case, it's easily a new high for electric cars. It comes at a price: US $94 900 to start for the Model S Performance edition, rising to $101 600 for the version

PRICE: US $101 600 (for the version tested), less $7500 U.S. tax credit **RANGE:** EPA-certified 265 miles (426 km) **POWER PLANT:** Rear-mounted 310-kW (416-hp) motor

I tested. (From that, deduct $7500 in the form of a U.S. federal tax credit.)

On an opening drive, the Tesla's enormous 85-kilowatt-hour battery indeed has me on pace for at least 426 km. The current flows from an under-floor sandwich of roughly 7000 Panasonic lithium-ion cells weighing some 590 kilograms (1300 pounds).

On a second-day run to Wisconsin, I nearly drain the battery after 320 km, but that includes two brutal, crawling hours in a Chicago traffic jam. That hard-charging day was also more about testing performance than range, including the Tesla's stealthy, 4.4-second blasts from 0 to 97 km/h (0 to 60 mph) and a 210 km/h top speed.

Did I mention that the 310-kilowatt (416-horsepower) Tesla will beat the monstrous, gasoline-powered 413-kW (554-hp) BMW M5 from 0 to 100 mph? Credit here goes partly to the 600 newton meters (443 foot-pounds) of torque available instantly from the Tesla's synchronous AC motor. Flick the Tesla's throttle like a light switch and maximum torque is on tap from 0 to 5100 revolutions per minute. The rear-mounted, liquid-cooled motor can hum to 16 000 rpm, linked to rear wheels by a single-speed gearbox.

The Tesla hunts down internal-combustion prey with eerily silent remorselessness—so silent, it must be said, that the noises from the tires and from wind resistance become more obtrusive than in most other luxury cars. The low-mounted battery gives the Tesla a center of gravity on par with that of many supercars, a boon to stable handling. And the Model S feels impeccably planted through curves.

Yet although the Tesla doesn't look heavy, it weighs in at 2108 kg, and the excess flab reveals itself as the speed and *g* forces climb. Push harder and the hefty back end bobs and weaves. When it comes to exhilarating handling, the Tesla is no BMW. It's not even a Mazda.

The whiz-bang begins before you climb in, with retractable door handles that automatically emerge as you approach. It continues with the Tesla's signature cabin feature, a 43-centimeter (17-inch) capacitive touch screen that looks like a pair of mating iPads.

Within its aluminum-intensive chassis and body, the Model S seats five. A cute-but-dubious option adds rear-facing child seats under the hatch for seven-passenger capability. Folding the second-row seats down expands rear cargo space to Home Depot proportions. And with no engine under the hood, there's room for a useful front trunk, or as Tesla calls it, a "frunk," as in a Porsche 911.

The EPA pegs the Tesla's mileage at the equivalent of 2.6 liters per 100 kilometers (89 miles per gallon), calculating that a liter of gasoline is worth 8.9 kWh. That works out to an annual fuel cost of $700, based on 12 000 miles driven and home electricity priced at 12 cents per kWh. Compare that with a mere 224-kW (300-hp) BMW 535i, whose 9.8 L/100 km (24 mpg) average will cost you $2250 a year in premium gasoline.

For home use, the Tesla's 240-volt, 50-ampere Mobile Connector restores about 50 km of driving range per hour with its 10-kW onboard charger. Double up with the 20-kW Twin Charger unit, with home 240-V, 80-A service, and you'll add 100 km of range for each hour on the plug.

On my first night in Chicago, I pull into the Radisson Blu Aqua Hotel and plug into one of three 240-V ChargePoint stations in an underground lot. In 6 hours, the Tesla's electric tank is replenished. The company has also begun installing proprietary 90-kW DC Supercharger stations on both coasts that can add 240 km of driving range in 30 minutes. Those fill-ups will be free for the life of the car, the company pledges.

With prices high and sales slow, Tesla badly missed 2012 production targets, although it insists it remains on track to build 20 000 cars this year. Success may hinge on new versions, which trade power and range for a lower price. Available later this year, a $59 900 Model S combines a 40-kWh battery with 175 kW (235 hp), enough to travel 257 km and hit 97 km/h in a respectable 6.5 seconds.

Throw in the $7500 federal tax credit and that Model S will start at $52 400, roughly on par with a six-cylinder Audi A6, BMW 5-Series, or Mercedes E-Class—fine German cars, one and all. But none of them will turn heads or blow minds like the Tesla Model S. ■

VOLKSWAGEN *XL1*

Voilá: The world's first production 1-liter car

VOLKSWAGEN BILLS ITS XL1, a plug-in, diesel-electric hybrid, as "the most efficient car in the world." The name reflects its claim to being the world's first production "1-liter car," able to go 100 kilometers on a liter of fuel—or 235 miles on a gallon. VW plans to begin selling small numbers of XL1s, likely in Europe only, by the end of this year.

The company went to extremes: Roughly as long as a subcompact VW Polo and as low as a Lamborghini Gallardo Spyder, the dolphin-bodied XL1 boasts a vanishingly low drag coefficient of 0.186. The carbon-fiber-intensive car weighs just 795 kilograms (1753 pounds), seats two occupants in offset side-by-side chairs, and integrates wing doors for easier entry and exit. A two-cylinder, 0.8-liter diesel puts out 35 kilowatts (47 horsepower), which combines with a 20-kW (27-hp) electric motor, a seven-speed dual-clutch automatic transmission, and a lithium-ion battery. The result is a leisurely 11.9-second squirt from 0 to 97 kilometers per hour (0 to 60 miles per hour) and a 160 km/h top speed.

But the XL1 is about saving energy, not time: The power it needs to cruise at a constant 100 km/h is less than what a typical ride-on mower uses to cut the grass: just 6.2 kW (8.3 hp).

FUEL ECONOMY: 100 kilometers on 1 liter of diesel fuel (235 mpg) **AERODYNAMIC DRAG COEFFICIENT:** 0.186 **POWER PLANT:** 0.8-L two-cylinder diesel, 35 kW (47 hp)

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PEACEFUL COEXISTENCE

The trials of a small team of engineers who set out to reanimate paralyzed limbs demonstrate the virtues of dynamic spectrum sharing

By Ariel Bleicher

ONE DAY IN 2003, JOSEPH SCHULMAN FACED A half-dozen or so military officers in a cheerless high-rise office outside the U.S. capital of Washington, D.C. He was 68 then, with piercing blue eyes and a full head of hair dyed chestnut. People who knew him called him a "visionary" and a "mad, brilliant scientist." For nearly 20 years, he had been president of the Alfred Mann Foundation, a medical research center in Santa Clarita, Calif., known for developing cutting-edge electronic aids, including pacemakers and cochlear implants. Normally a self-assured guy, Schulman suddenly felt, he says, "a little frightened." ● He had come to what was then the Defense Spectrum Office to present his case for allowing a new medical technology to use some of the radio frequencies assigned to the U.S. military. He began by pulling from his pocket several small ceramic cylinders, which he passed around.

SHARE AND SHARE ALIKE: Medical device engineers Howard Stover [left] and Joseph Schulman envisioned a wireless nerve network that could share spectrum with powerful military radios.

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Those fuse-like tubes, Schulman explained, were intended to restore function to muscles whose nerves had been damaged. "Microstimulators," he called them. A surgeon could implant one in the body simply by using probing tools and a syringe. Inside the microstimulator were a battery and electronics, which controlled a pair of electrodes that could send pulses of current into a paralyzed limb. The electrodes could also pick up signals from healthy nerves, such as in the stump of an amputated arm, where the devices could be used to guide a prosthetic hand.

To perform these tasks, the microstimulators would need to be controlled by a pocketable radio. It was important that this be done wirelessly. Placing wires inside the body would take time, raising the risk of surgical complications and providing conduits for bacterial infections.

The trouble was that operating a wireless network of tiny implants in the body's wet, salty interior required a special portion of radio spectrum. And Schulman knew the military owned the rights to it. But he believed that if he just asked nicely, he could persuade the uniformed men across the table to share a slim slice of their electromagnetic pie with this potentially revolutionary invention, seeing as it might one day help wounded soldiers.

"I was naive," Schulman says. In fact, the spectrum campaign he began in 2003 lasted eight years and cost the foundation more than US $3 million in travel expenses, legal fees, and independent testing. But the quest proved more than a simple fight for frequencies. In their drive to get microstimulators on the market, Schulman and his colleagues would find themselves swept up in a monumental restructuring of the divisions that make radio spectrum artificially scarce.

Since the invention of radio, people have had to figure out how to share the spectrum. Early wireless telegraphs, which appeared in the late 1800s, were colossal spectrum hogs. Operators attempted to avoid interference by listening to one another and taking turns sending signals. A common message was GTH OM QRT ("Go to hell, old man, and keep quiet, I'm busy"). By the early 1900s, hundreds of stations in the United States were trying to talk over one another. Then on 15 April 1912, the ocean liner RMS *Titanic* sank. An investigation revealed that jabbering shore operators had hampered communications with the rescue ship. The incident reinforced an already growing opinion among lawmakers that rules were needed to establish order on the airwaves.

The Radio Act of 1912 empowered the U.S. government to control radio usage by issuing licenses, parceling out spectrum as if it were land. Later acts further refined the rules, eventually establishing two distinct regulatory bodies: the National Telecommunications and Information Administration (NTIA), which manages the federal government's spectrum use, and the Federal Communications Commission (FCC), which manages everyone else's.

As wireless technology evolved, outmoded bands were cleared or subdivided to make way for new services. Often, regulators permitted more than one service to occupy a single band, and many federal users shared bands with nonfederal ones. To prevent interference, they were expected to coordinate their use, for example by divvying up frequencies, locations, or time slots. Interested parties collaborated, as most still do, through trade associations or with the help of consulting engineers.

This approach worked well—for a while. But as radios proliferated in the decades after World War II, bands filled and competition for spectrum grew. As the end of the 20th century approached, network operators, particularly mobile phone companies struggling to meet exploding demand for data, were lobbying fiercely to take over federal frequencies and offering hundreds of millions of dollars to buy still more spectrum from their competitors. Increasingly, there was talk of spectrum scarcity, shortage, and "drought." Would there be enough of the precious stuff to go around?

Meanwhile, radios were getting smarter. Under software control, radios could now switch between multiple frequencies, waveforms, transmission protocols, or applications.

One of the most ambitious early attempts to make use of this new agility began in the late 1990s at the U.S. military's "mad-science" arm, the Defense Advanced Research Project Agency (DARPA). The project's main goal was to create a network of portable radios that could overcome the disorderly spectrum environment of a battlefield. To accommodate data and video as well as voice, many of the radio channels would need to be very wide—about 10 megahertz, almost twice the bandwidth of a television channel. But when the project's manager, Mark McHenry, pitched the idea to the military's spectrum managers, he got the cold shoulder: "They told me, 'There's no way you can get that much spectrum.' "

But McHenry didn't leave things there. He wondered how much of the supposedly crowded spectrum was really being used at any one time and place. So he commissioned a small study that measured all the radio activity in a large U.S. city during one week. Others may have had their suspicions about spectrum lying fallow, but McHenry was the first to gather hard data. And the results he got were surprising.

"The spectrum was absolutely empty," he recalls. "It was 90 percent holes!" Radio spectrum was available, and there was plenty of it. The holes, or "white spaces," were just waiting to be filled. But how?

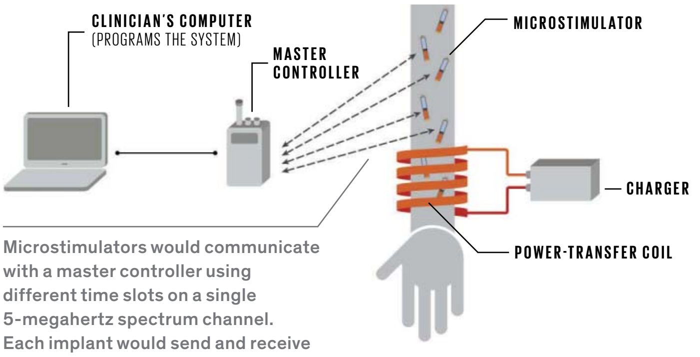
That was the challenge. Unlike fixed band assignments, white spaces are dynamic; they vary by geographical location, and they can appear and disappear over time, often unexpectedly. To take advantage of them, a radio would need to know how other radios are using the airwaves and what the rules are. This could be done, for instance, through access to an Internet database of select white spaces, such as those left by television stations that don't air in certain cities. Better yet, the intelligence for sensing and analyzing spectrum could be built into the radio itself—a holy grail known as cognitive radio.

DARPA accepted the challenge. In 1999, the agency created the neXt Generation Communications program to study what it called dynamic spectrum access. From there the concept spread, albeit slowly. The first civilian foray into this new territory came in 2003, when the FCC allowed unlicensed radios, including Wi-Fi routers and wireless broadband equipment, to share spectrum with government radars, such as those that airport weather forecasters use to detect brewing storms. To avoid compromising these critical radars, an Internet radio must "listen" to the airwaves before selecting a frequency and shift to a new channel when the one it's currently using becomes occupied.

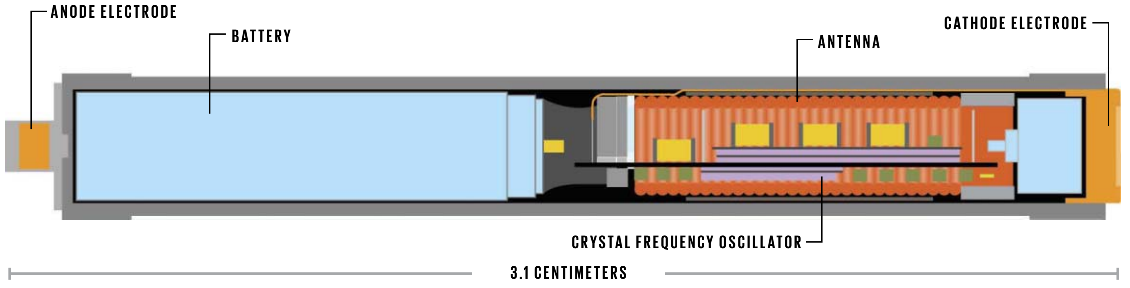
PHOTOGRAPH, PREVIOUS PAGES, BY Gregg Segal

A WIRELESS NERVOUS SYSTEM

The Alfred Mann Foundation aims to develop a network of tiny electronic implants that could sense and stimulate muscle movements, helping to treat paralysis or control a prosthetic limb.



Microstimulators would communicate with a master controller using different time slots on a single 5-megahertz spectrum channel. Each implant would send and receive 90 messages per second.



Around this time, Schulman and the other engineers at the Alfred Mann Foundation were realizing they needed to find white spaces of their own. The microstimulator's power and stimulation schemes had been mostly worked out, and the team now faced the challenge of designing the communication system.

The technical demands were significant. Schulman determined that if a microstimulator were to simulate real nerve impulses, it had to receive about 20 intelligible messages per second from a master controller carried outside the body. But some transmissions were bound to get lost or garbled. So the engineers figured that each implant ought to receive and transmit a message about 90 times per second.

Altogether, the system had to be able to handle as many as several dozen—and perhaps one day even hundreds—of devices inside a person's body. By permitting only one microstimulator to link up with the master controller at any given instant, the engineers could build them so that they all shared a single radio channel. But to conserve its tiny internal battery for other tasks, such as stimulation, each implant could use its radio only 0.1 percent of the time. The engineers calculated that the battery could then last for about three days before needing a recharge. (This would be done wirelessly, using a magnetic coil.)

Limiting the radio's "on" time, however, presented a problem. It meant the system had to communicate sizable chunks of data in very short bursts. The dispatches required some 5 MHz of bandwidth, about the same as one television channel. Where could the engineers find that much spectrum?

Initially, Schulman ignored the question. "He thought the political problems were much smaller than the technical problems," remembers Howard Stover, who headed the communications team. Stover sports the hallmarks of a fine engineer—suspenders, glasses, a beard, an affable chuckle. "Joe's attitude was, 'Just make it work. We'll figure out all that other stuff later.' "

Stover thought that was the wrong attitude. He saw no sense in putting time and effort into engineering a product no one could legally use. So he thought about how to tackle the spectrum problem.

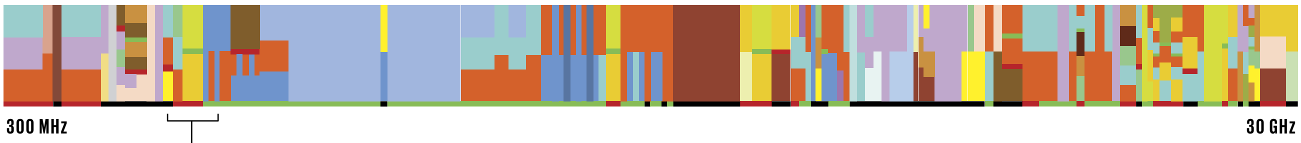
Four years earlier, in 1999, the FCC had designated a thin tract of frequencies near 400 MHz for what it called the Medical Implant Communications Service, intended for the radios in hearing aids, pain pumps, and heart defibrillators. In some ways, this band seemed ideal for microstimulators. Its prime attraction was its position on the spectrum: The frequencies were high enough to work with short antennas yet low enough to easily penetrate human tissue.

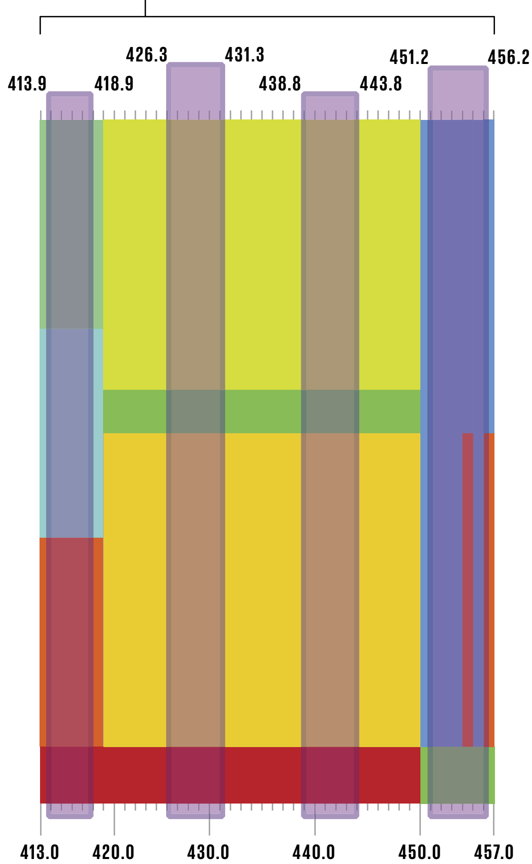
But this band had one big flaw. Although it was 3 MHz wide—almost enough bandwidth for microstimulators—the FCC limited radios to transmitting on only 300 kilohertz at a time while using no more than 25 microwatts of power, about 1/40 of the power a master controller needs to talk to microstimulators. The rules were meant to prevent interference with other low-power systems, such as weather probes, that share the same frequencies. But the rules made the band useless for microstimulators.

Not far away on the spectrum, however, was a band about 30 MHz wide that amateur radio operators share with the U.S. military as secondary users, meaning the hobbyists can use the airwaves so long as their equipment doesn't interfere with defense systems. The bandwidth and power constraints here were much more lax. And Stover thought he knew how to persuade the amateurs to let microstimulators use some of the frequencies. Being an old "ham" himself, he was aware that amateurs were in constant fear of having to vacate the band. He could make the case that they would gain some staying power by sharing these airwaves with microstimulators. Surely no one would kick out a medical technology.

ILLUSTRATION BY Emily Cooper

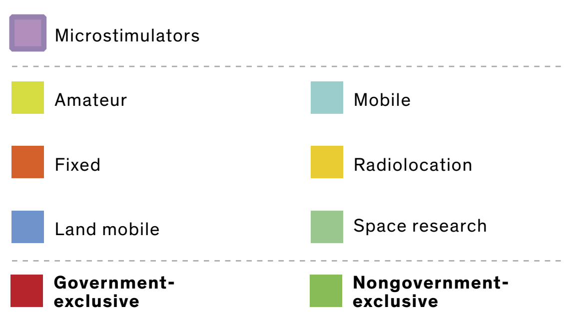
U.S. radio frequency allocations





SMART SPECTRUM SHARING

New wireless technologies are struggling to find space on the cluttered radio spectrum without interfering with other users. The Alfred Mann Foundation's microstimulator network solves this problem by utilizing multiple bands: If the system encounters more noise than it can handle on one frequency, it simply hops to another.



Stover prevailed upon Schulman to pitch the idea to representatives from the American Radio Relay League in Washington, D.C., the largest association of radio amateurs in the United States. The amateurs listened, but they expressed concerns about interference, and besides, they didn't have much say in the matter. It wasn't their spectrum to share. They suggested that Schulman approach the Defense Spectrum Office. When he met with the military officers there in 2003, they in turn referred him to the FCC and the NTIA, which must coordinate their decisions when a private party wants to use federal government spectrum.

After that, Schulman flew to Washington, D.C., almost every other week. The first few times he went alone, and in this respect he was like dozens of other innovators who come knocking on the doors of the two regulatory agencies every year looking for spectrum. "They have this great idea, but they have no idea about how spectrum management or the FCC works and how to take an idea and bring it to fruition," says Julius Knapp, chief of the FCC's Office of Engineering and Technology. Knapp's first advice to Schulman was to get a lawyer.

At first it seemed Schulman was getting nowhere. "To be perfectly blunt, the two parties started 180 degrees apart," remembers Edward Davison, who chairs the Interdepartmental Radio Advisory Committee (IRAC), which advises the NTIA on spectrum matters. "The Alfred Mann people thought things were going to be easy and the [Department of Defense] thought things were going to be impossible."

The military's main concern was interference. Microstimulators would have to operate in the same spectrum as high-power defense systems. "We're talking about *mega*watt radars," says Fred Moorefield, who was IRAC's Air Force representative and the main liaison between the Alfred Mann Foundation and the military. No one worried, he says, about one-milliwatt microstimulators wiping out the military's air-defense system. Rather, the scenario Moorefield and others feared most was that the radars would disable the microstimulators, with the disastrous outcome of both injuring patients and inciting empathetic lawmakers to kick the military out of the band. At

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ILLUSTRATION BY Erik Vrielink

the time, the military was facing a watered-down version of this very issue: Since their rollout began in 2004, new defense radios had reportedly impaired tens of thousands of garage-door openers, which used some of the military's spectrum on a secondary basis.

But the radios in microstimulators were a lot more sophisticated. Using custom codes and protocols, they could already handle a fair amount of interference. Moreover, Stover's team cleverly equipped the master controller with complex algorithms to essentially "notch out" radar and other fleeting narrowband signals from the faint wideband messages emerging from the body—like a cloud re-forming after a bullet passes through.

The military experts weren't satisfied. These protections were nice, they said, but a big radar at close range could still overwhelm the system. What then?

Had this scenario played out a decade earlier, prospects for microstimulators might have ended then and there. But by the mid-2000s, spectrum regulators at the NTIA were warming to the idea that radios could be smart and flexible. So they suggested to Schulman and Stover that they design their system to work on more than one channel. Make it more dynamic, they said. They thought three was a good number. Maybe add a fourth channel outside the military's spectrum, just in case the microstimulators happened to be inside a soldier.

One afternoon, Stover sat down with a chart listing all the frequency assignments in the candidate spectrum plot and carefully selected four 5-MHz-wide bands, taking pains to avoid other low-power users, which the microstimulators could potentially disturb. These included satellite rescue beacons, radio telescopes, RFID tags, and amateur receivers used to capture very weak signals bounced off the moon. Stover chose two bands that would be shared with military radars and a third with fixed, mobile, and space research systems. The fourth band contained mostly civilian walkie-talkies and "remote pickup" equipment that television crews use to beam field reports back to a broadcast station. That last band wouldn't be much use in cities, but it could be vital on military bases.

Together, the four bands could make the system reliable. Spectrum measurements showed it was a pretty sure bet that at least one—and more often two or three—would be available at any given time. That way, if the master controller encountered more interference than it could handle on one band, it could simply move the system to another. On the very rare occasion that all four channels became too crowded to use, the microstimulators would execute a preprogrammed series of actions to power down in a controlled fashion. "A graceful shutdown," Stover calls it.

After Schulman retired as president of the Alfred Mann Foundation in 2007, his successor, David Hankin, took up the baton. As a leader, Hankin was antipodal to Schulman in almost every respect. Trained as a lawyer and a businessman, he was a savvy negotiator. He thought that the problems posed by politics were at least as important as the problems of engineering, if not more so. If Schulman was the visionary, Hankin was the executor. He lobbied politicians, had the foundation's lawyer draft a formal proposal for the FCC, and kept in constant contact with staff there and at the NTIA.

Hankin also pushed Stover and the engineering team to ready the microstimulator's communication system for prime time. Then he hired people outside the foundation to test it—people whom the military agreed would do a reliable, unbiased job. The independent evaluations cost the foundation several hundred thousand dollars and took more than a year, but they proved to be a turning point. Hankin filed the test reports with the FCC and sent copies to Moorefield. He and the other military experts were impressed. "So we said, 'Yup, we like it. We think it does what you say,'" Moorefield recalls. "Let's do it."

At last, in November 2011, the FCC authorized microstimulators to operate as a secondary service within the four designated spectrum bands, provided that the radios dodge harmful interference by hopping from one band to another on the fly. In a statement he read after announcing the new law, FCC chairman Julius Genachowski praised the foundation's efforts, calling the outcome a "model for making more efficient use of radio spectrum."

Over the past decade, the FCC has approved the use of dynamic sharing in other contexts as well, starting with wireless broadband services back in 2003. In 2008, Wi-Fi and other unlicensed radios were allowed access using Internet databases to the white spaces between television stations. In 2012, wearable health sensors such as glucose monitors were welcomed into spectrum that the aerospace industry uses for flight testing. And later that year, the FCC proposed opening 100 MHz of government spectrum to miniature base stations, known as small cells.

Even mobile-phone companies, which continue to push hard for clearing federal frequencies for their exclusive use, are warming to sharing. This January AT&T, T-Mobile, and Verizon announced an agreement to explore the possibility.

Moorefield says he now advises anyone who comes asking for bits and pieces of the military's spectrum to follow this model. "The mantra today is sharing," he says. "I think the old way of thinking—where you had segregated spectrum, move-me-out-so-that-someone-else-can-move-in spectrum—I think those days are over."

On a crisp, sunny afternoon last November, Hankin, Stover, and two engineers gathered around a conference table at the Alfred Mann Foundation. They were trying to remember whether they had believed their crusade for spectrum would ever succeed.

"I thought it was going to be difficult."

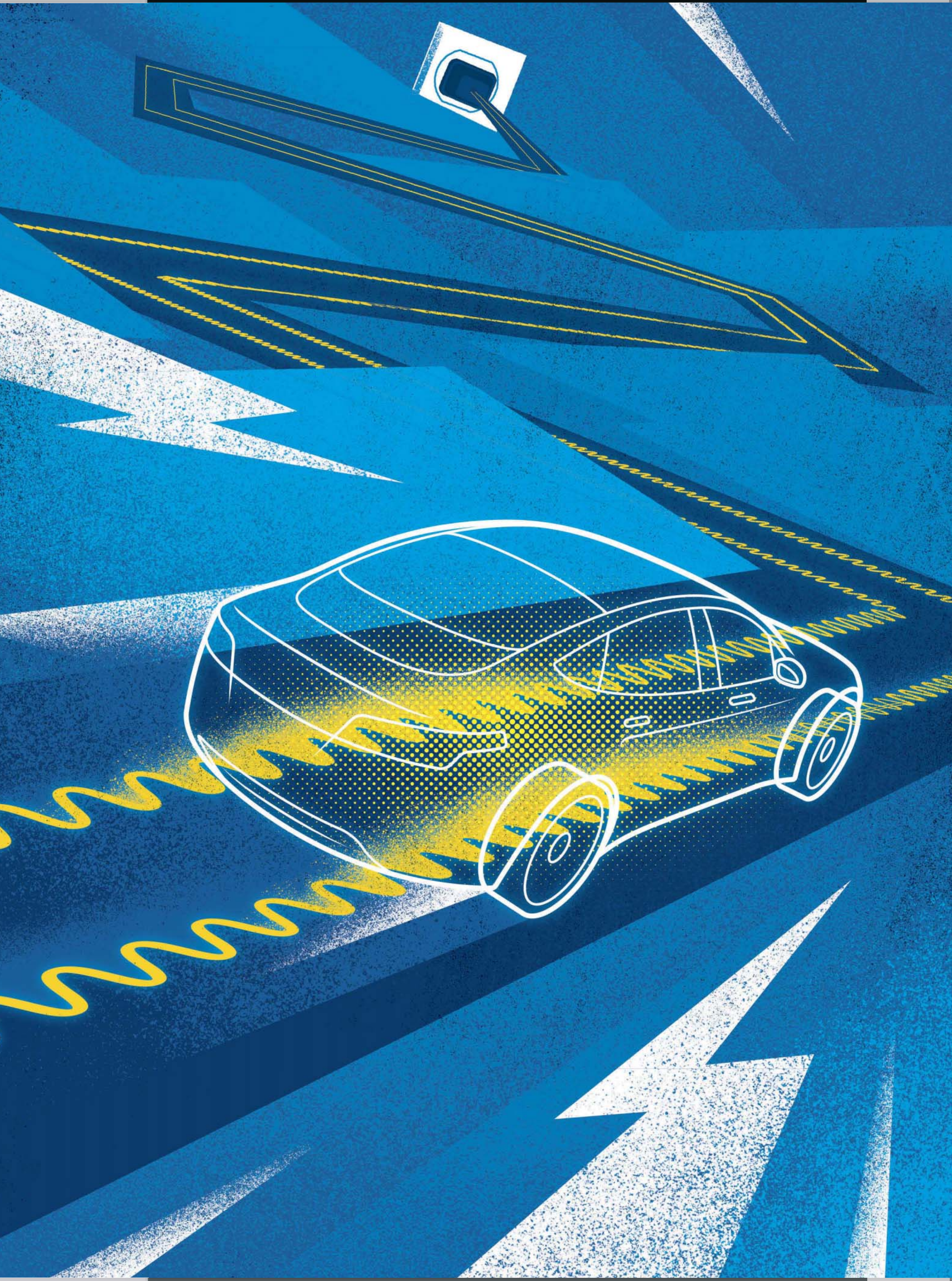
"I thought it would be impossible."

"Why? Because who the hell are we?"

"We're a small, tiny research foundation in California," Hankin said. "The military guys, they don't know us from anybody. And we're knocking on their door asking to use valuable spectrum that they have some of their most precious installations in. And they're asking 'Why? What are you going to do for us that's so meaningful?' "

Hankin went on to describe a time during the spectrum debates when he brought a few military experts to visit an Army hospital in Maryland where the foundation had previously tested an early version of the microstimulator. The test patient, having damaged his spine, had trouble moving his legs, and his doctor had injected four stimulators into his thighs, which helped him regain some motion. The experts spent 2 hours talking with the doctor and visiting other patients, many of them young soldiers who had lost limbs in Iraq or Afghanistan.

"This," Hankin concluded, "was their answer." ■



CHARGING UP THE ROAD

IF ELECTRIC VEHICLES COULD DRAW POWER FROM THE STREETS, THERE'S NO TELLING HOW FAR THEY COULD GO

BY SEUNGYOUNG AHN, NAM PYO SUH & DONG-HO CHO

PICTURE AN ALL-ELECTRIC VEHICLE cruising down the highway, emitting little noise and no noxious fumes. It's such an improvement that you have to wonder why only a handful of all-electric vehicles are now available on the mass market. • Here's a big reason: Picture the driver of that same car getting a call from a relative living far away who needs immediate help. Suddenly, the driver's eyes become riveted on the most important indicator on the dashboard: the estimated number of kilometers that the car can go on the remaining battery charge. Will he make it to his relative's house? Even if he does, will he find a charging station so he can get back home?

ILLUSTRATION BY James Provost

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THERE'S A NAME for this modern misgiving: range anxiety, a new form of disquiet experienced by drivers of all-electric cars. The Nissan Leaf, for example, can be driven on the highway for only about 120 kilometers on a single charge, and fully charging up its batteries takes 8 hours or more. • But maybe there's a way to relieve this fear forever and make drivers' lives much easier as well. If we embed transmitting coils in roadways, electric cars carrying receiving coils could charge themselves as they zoom down the road. An e-car owner would never have to search for a charging station or plug in the car. That is the goal of our research team at the Korea Advanced Institute of Science and Technology (KAIST), in Daejeon, which has developed what we call the on-line electric vehicle (OLEV) system.

WIRELESS POWER TRANSMISSION isn't a new idea: Nikola Tesla built a 57-meter-tall tower behind his lab in Shoreham, N.Y., in the first years of the 20th century, partly to beam power to remote equipment. But only in the past decade have researchers begun to make the breakthroughs that can allow for commercially practical wireless charging, not only for portable electronic products like smartphones but even for industrial robots and electric cars.

The technology depends on the same principle of electromagnetic induction that enables a transformer to change the voltage of an alternating current. This current flows through one coil of wire, creating a magnetic field whose polarity reverses with each cycle and inducing a corresponding alternating field in a secondary coil. The ratio of the number of turns in the two coils determines whether the transformer steps voltage up or down. Transformers usually include an iron-rich core, which links the coils and increases the field strength, but you don't really need it. If the two coils are separated by air, current flowing through the first coil will still create a magnetic field, which will still be picked up by the second coil—it just won't be picked up as well. The greater the air gap, the less efficient the transfer of power will be.

More than 90 years after Tesla began building his tower, an ambitious project in California tried to apply his concept of wireless power transmission to automobiles. In 1994, the Partners for Advanced Transit and Highways project, led by researchers at the University of California, Berkeley, demonstrated the transfer of power from coils buried in the road to the cars above. It worked whether the cars were at rest or in motion. The receiving coils were on the underside of the test vehicles and were separated from

A TRAM UNBOUND by cables tours a Seoul city park [top]. Clockwise from middle right are the wireless transmitting coils, to be buried in the road; pipes (with a magnetometer) that convey power to the coils; a tuning station to match the coil's frequency to that of the tram's receiver; and an inverter, which supplies high-quality AC power only when the tram is above the charging line.

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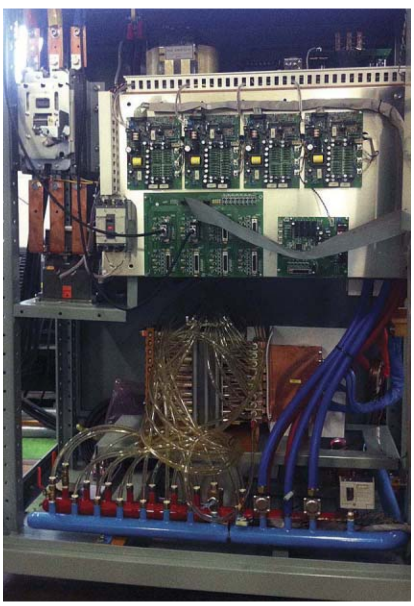
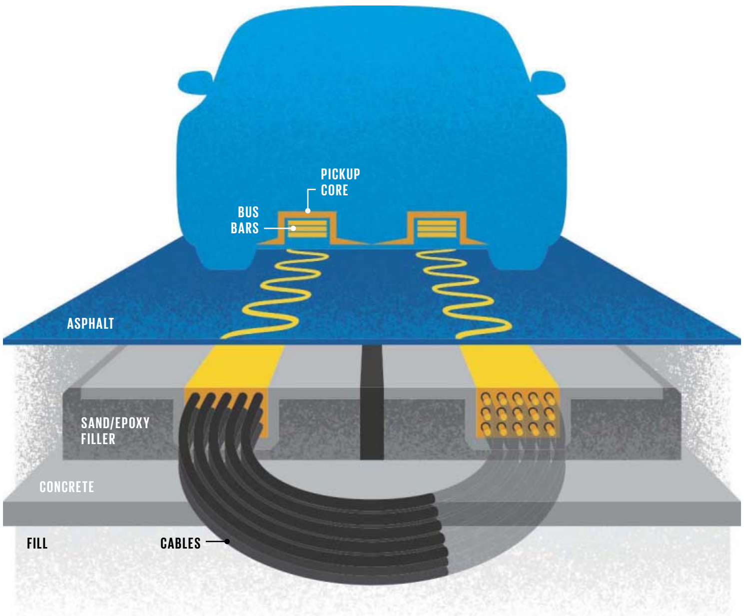


KOREA ADVANCED INSTITUTE OF SCIENCE AND TECHNOLOGY (5)



THE FORCE IS WITH YOU

An electric car can draw power by establishing resonant coupling between the electromagnetic field of the buried transmitting coils and that of the pickup coils under the car. Efficient resonance happens when the transmitter's frequency is tuned to the pickup circuit; efficiency is enhanced further by ferrite cores, which shape the field.

the transmitting coils by an air gap of only 7.5 centimeters. They captured 65 percent of the injected power, an impressive achievement at the time. But still, a scheme that wasted a full 35 percent of the power could not be brought to market, and an air gap that narrow would have required hanging the receiving coils so low that a bump or a pothole could have sheared them right off.

How, then, to increase the efficiency of the power transfer without having to make the low-slung receivers even more vulnerable? The answer that we and other researchers have recently settled on is called magnetic resonance coupling.

A familiar illustration of the power of resonance is that of the opera singer and the wine glass. As the diva warbles, the acoustic waves hit the glass, causing it to vibrate; if she hits the note with the same natural frequency as the glass, each cycle will amplify the vibrations until finally they are strong enough to shatter the glass. The singer's voice enters into a special relationship with that glass, passing more energy to it than to other, nonresonating items in the room. Similarly, when a transmitting coil sends electromagnetic waves tuned to a frequency matching the resonance of a circuit holding a receiving coil, it will transfer energy to it very efficiently.

Researchers around the world have begun applying this principle over the past decade. In 2007, MIT professors caught the world's attention by powering a lightbulb suspended in space, 2 meters away from the transmitting coil. Those researchers went on to found a Massachusetts start-up, WiTricity Corp., which is working with several auto companies on wireless charging stations for household garages. Quebec's Bombardier is developing its Primove system in Europe to transmit power to public buses and trams.

Our research at KAIST began in 2009 when one of us (Suh) identified battery-powered electric cars as a technology that would work far better if these cars didn't have to lug around such huge, expensive batteries. Suh met with Myung-bak Lee, then the president of South Korea, and proposed that KAIST develop wirelessly powered vehicles. The National Science and Technology Council allotted the enterprise US $25 million, and our OLEV project was ready to roll.

ON A COOL MARCH DAY IN 2010, a distinguished group of scientists and politicians gathered in Seoul Grand Park to witness the inaugural run of a bright green-and-blue tram wreathed in flowers, with the words "Seoul Zoo" painted on its nose. Se-hoon Oh, then the mayor of Seoul, declared that he expected wirelessly powered buses and trams to be "the environment-friendly transportation in the future."

Today the OLEV tram is still zipping around the park on a 2.2-km loop of roadway, 370 meters of which has transmitting coils embedded in the asphalt. As the tram rolls along, magnetic sensors in the road detect its approach and activate the transmitters to send 62 kilowatts to the receiving coils on the underside of the tram. Meanwhile, the tram operator keeps an eye on a monitor that shows how well the tram is aligned with the transmitting coils it passes over, and thus how efficiently it's receiving power. (We are developing a system that will align the vehicle automatically by measuring the strength of the magnetic field.) The bus still contains a battery, but it carries 40 percent less energy than it would have to otherwise. It's also 6 percent lighter, at 1100 kilograms, and significantly cheaper, costing $88 500.

The key advances our team made are in the design of the electromagnetic field. The first decision had to do with the relative strength of the two component fields—electric and magnetic. An engineer can choose which field to favor. For example, a dipole antenna generates a stronger electric field, and a loop antenna generates a more powerful magnetic field. We chose a dual loop design for the buried transmitter because magnetic fields are better at transmitting power through asphalt, dirt, and other substances that may come between the transmitter and the receiver.

The second decision was to increase the efficiency of this power transmission with a shaped magnetic field—one whose path from the transmitter coil to the receiver coil is guided by the presence of ferrite

ILLUSTRATION BY James Provost

cores on both sides. This arrangement minimizes field leakage and hence waste. In recent experiments with an OLEV bus, we charged the bus while it was being driven, its body 20 cm above the road, and achieved an average transfer efficiency of 75 percent.

Whereas experimental wireless charging stations for household garages can now transfer a measly 3.3 or 6.6 kW, the OLEV bus received 100 kW of power while in motion. You need such high power to propel heavy buses full of people and to reduce charging time. By embedding the transmission coils at points where vehicles stop and linger, like parking garages, bus stops, taxi stands, and traffic lights, we plan to charge the vehicles more efficiently and also reduce investments in construction. After all, if vehicles spend a lot of time standing in place, why not put the chargers in those places?

We also took great care in selecting the resonance frequency for our OLEV system. As you raise the frequency through the kilohertz range, you induce proportionally higher voltage in the receiving coils and gain better transfer efficiency. As the frequency rises above the megahertz range, however, the cables for the transmitting and receiving coils suffer from what's called skin effect: Current flows in an ever-thinner surface layer whose depth is inversely proportional to the square root of the frequency.

In an aluminum cable, the skin depth at 100 kHz is 0.25 millimeters, which you can deal with just by using suitably fine strands of wire. But at 10 megahertz, it comes to just 0.024 mm, which is tougher to deal with. Also, as the frequency mounts from the kilohertz to the megahertz range, our inverter's switching device–an insulated-gate bipolar transistor–becomes dramatically less efficient at turning DC power into AC.

We used 20 kHz as the operating frequency in an OLEV bus demonstrated at Expo 2012, in Yeosu, South Korea. By July, we expect to have the world's first commercial trial of such a bus up and running, in Gumi, South Korea.

In the next phase of the project, we'll apply the OLEV technology to a high-speed railway system and make it even speedier. Today's system limits the train speed to less than 300 kilometers per hour, because it picks up power from the cable by means of a spring-like metal link. Wireless transmission can free the train of this encumbrance, allowing it to reach faster speeds and negotiate narrower tunnels. In February, we demonstrated in the lab a 180-kW system for wireless power transfer that runs at 60 kHz (an operating frequency we have recently been able to achieve by redesigning the inverter). We expect to integrate this system into a railway vehicle by the end of the year.

Another interesting application of OLEV technology we are investigating is in ports, for the small vehicles used to move shipping containers. The limited field of required movement in that setting should make it particularly easy to embed power transmitters in the ground.

OUR WIRELESS SCHEME still faces many challenges, above all the possibility that the electromagnetic fields it generates might be a threat to people's health. In Korea, as in most countries, the safety limit for magnetic field exposure has been set at 6.25 microteslas.

The United States sets a much more lenient 205 μT, for the frequency range between 3.35 kHz and 5 megahertz.

It is a simple matter to stay below even the Korean limit inside a typical car, bus, or train whose structure is largely metallic. The metal body of our OLEV bus provided enough passive shielding to keep the magnetic field under 2 μT in all positions. Just to be sure, we also developed a complementary system that could hew to the 6.25-μT standard under all conditions–active shielding, which involves surrounding the passenger compartment with current-carrying wires that generate magnetic flux opposite to that of the external field.

Then there are the technical constraints: To match the 85 km/h maximum speed of a gasoline- or diesel-powered city bus requires a power transfer of 100 kW. That's all the bus can use; most of the time it will consume less and divert the rest to the batteries. To match its total, inclusive energy efficiency–calculated on an "oil-well-to-bus-wheel" basis–the transmitting and receiving coils must be large enough to make use of at least 80 percent of the 100 kW while maintaining a gap of at least 20 cm between the road and the bottom of the bus.

Efficiency is always important, but it can be critical in high-power applications like railways and seaports because power losses translate into waste heat, which can be difficult to remove. One way to improve efficiency is to put the generating plant closer to the ultimate user. Or you can transmit power over long distances as high-voltage DC or as low-frequency AC (which induces less of a skin effect), and then convert the power to 20-kHz AC at the destination.

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The second technical problem is how to make the pickup module light and compact enough to use in small air-gap trains, trams, buses, and cars. One new design uses coils that are wrapped around a thin core. We also hope to improve the transfer of power by raising the frequency of the shaped magnetic field above its current limit of 60 kHz. To do that, though, we must first find a way to get our inverter to work well at higher frequencies.

The biggest hurdle of all, though, isn't technical–it's economic. A manufacturer would need to find less expensive ways to build a wireless power-transfer system than we've been able to come up with. Construction of the 2.2-km loop at the zoo, for example, cost $550 000.

But we think overcoming these obstacles will be well worth the effort. Many leading automotive companies are building or planning to build electric vehicles, and some are already adopting wireless charging systems. Qualcomm has acquired HaloIPT technology for wireless charging. Nissan will soon be selling an electric vehicle capable of charging wirelessly while sitting in a parking lot. At the 2011 Tokyo Motor Show, Toyota and Mitsubishi showed an electric vehicle designed in collaboration with WiTricity. And Evatran, a U.S. company based in Wytheville, Va., has built a wireless charging system for the Nissan Leaf and the Chevy Volt.

The time has come to cut the cord–the power cord. There is no better way to realize the dream of the nonpolluting car. ■

CONTINUED FROM PAGE 28 | a couple during the 0.1 nanoseconds that the fuel is under peak compression. Instead of appearing as a perfect circle, the outer edge of the compressed fuel looked more corrugated–a bit like a four-leaf clover. Fixing that coarse asymmetry by updating the codes and further fine-tuning the beam targeting, Lindl says, could go a long way toward pushing the team closer to ignition. But he stops short of saying that it will be sufficient.

Like other fusion researchers, who think in terms of decades, Lindl bristles at the suggestion that a "grand challenge" like ignition could be accomplished on a strict deadline specified years in advance. "I think the progress has been remarkable," he declares, citing advances the team has made in fabricating targets and ramping up the laser power.

I ask him about one parameter that is often cited as evidence of slow going at NIF: the ignition threshold factor (ITFX), a number that acts more or less as a stand-in for pressure. An ITFX of 1 is thought to match what would be needed to break even, with as much energy in as energy out. After starting out with an ITFX of 0.001 two years ago, for the last year or so NIF has been stalled at an ITFX of 0.1. But Lindl says that this simple number hides some notable progress: The team has found ways to get to the same pressures while driving the fuel inward more slowly. That accomplishment might help them get to ignition by reducing the chance of cracking the ice layer. "We're awfully close" to ignition, Lindl says. "You don't change horses at this point."

LINDL AND HIS COLLEAGUES will get more time to prove that ignition is possible. In the wake of the National Ignition Campaign, the plan that set a 30 September deadline for ignition, the NNSA hopes to scale back the number of shots dedicated specifically to ignition from 80 percent to 40 percent, in part to help clear a backlog of stockpile stewardship shots. The NNSA plans to give NIF three years to pursue ignition before assessing the facility's prospects again.

Researchers say there is plenty to be excited about. The facility has only started to ramp up shots for basic research, which scientists hope could help illuminate complex questions related to stellar physics and planetary interiors, among other topics.

And a number of people say that NIF has already accomplished something big. Charles Verdon, principal deputy of Livermore's Weapons and Complex Integration Directorate, says the facility has helped clear up an unresolved question about energy balance, the way that X-rays from the primary, fission-dominated component of the nuclear warhead are carried to the fusion-dominated secondary. For half a century, Verdon says, weapon designers had to introduce a "fudge factor" to account for discrepancies between the expected performance and the data coming from underground tests.

"The fudge factor's been around since the first nuclear explosions way back in the '50s, when I was a kid and I'd watch the sky light up over L.A. from the explosions out in Nevada," says Robert Byer, a physicist at Stanford University who led a recent review of the facility. "It's amazing," he says. "NIF solved a problem that's crucial for our weapons systems understanding."

But when it comes to ignition, the picture is a little blurry. Those in the know simultaneously play up NIF's importance to stockpile stewardship and downplay the consequences should NIF fail to achieve an energy-surplus ignition. Many say the U.S. stewardship effort is already quite healthy, buoyed by hundreds of historic nuclear tests and few changes to designs since then. "Not having ignition in the laboratory is not a showstopper, but it does take off some future options," says NNSA's Deeney. "It would impose some limits on how we would handle change [to nuclear weapons] in the future."

Texas A&M's Adams urges the public not to read too much into the shortcomings of NIF's simulations. "If you look at what's going on at NIF in the stretch to try to reach ignition, those are tremendous excursions from previous experiments," he explains. "We've never had access to this much laser energy before, never tried to do anything like it."

"I'm not going to tell you that the stockpile would fall apart if we didn't have NIF or that it will fall apart if we don't get ignition, because I don't believe it will," Adams adds. "I think we will maintain a safe, secure, and effective stockpile, but our choices will become more limited."

NIF's impact on fusion power is also difficult to evaluate. Livermore has heavily publicized its scheme for a power plant based on NIF, called Laser Inertial Fusion Energy (LIFE). But even if NIF does reach ignition, critics point out, it will likely do so just barely. And that means that the agenda for a commercial power plant may not advance much. Analysis suggests that to be practical a fusion power plant would need to produce 50 times as much energy as went into the operation of the facility. Fuel pellets would have to be produced in vast numbers for about 25 cents each; Deeney reckons their current cost is more than $10 000 per pellet.

There are also materials issues to contend with: The neutrons created in fusion can degrade materials such as steel and render them radioactive. LIFE's approach is to use conventional steel that can be swapped out every few years; that may not be the best approach for a commercial plant.

But all of that is years away, at least. And if NIF fails to reach ignition, this particular approach will likely remain so. When it comes to fusion power, says Stanford's Byer, "most people throw their hands in the air and say it will never happen." Then again, he says, defense research can produce great and unexpected things: Without nuclear weapons, he notes, we might never have gotten conventional nuclear power plants. He could have added nuclear medicine and high-speed computing to the list. Although things may look dark now, for all we know the path to a brighter future might just be paved with lasers–192 of them. ■

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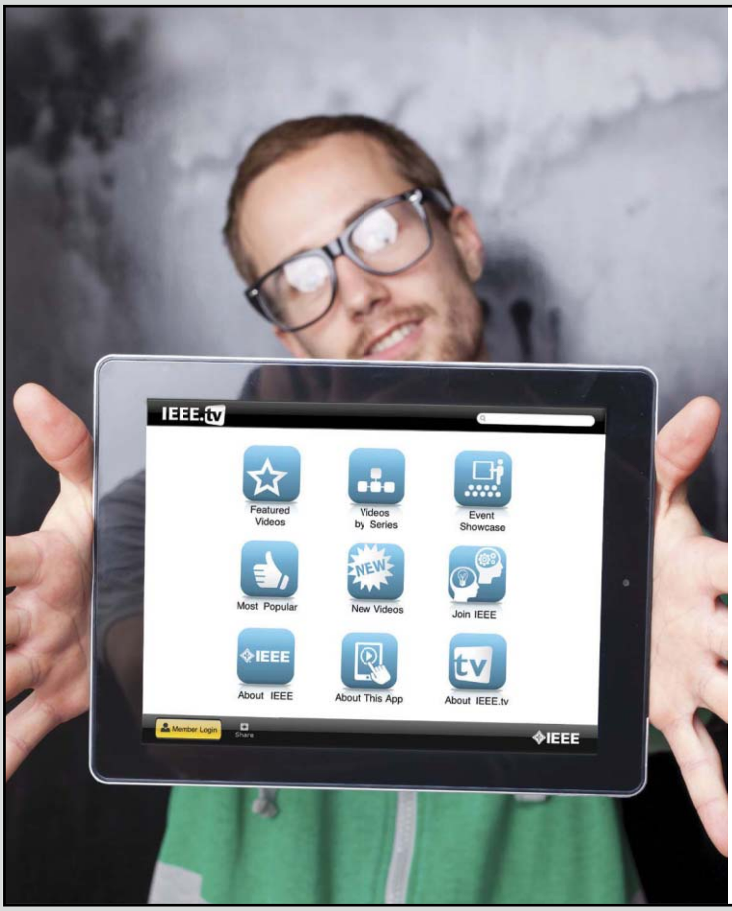
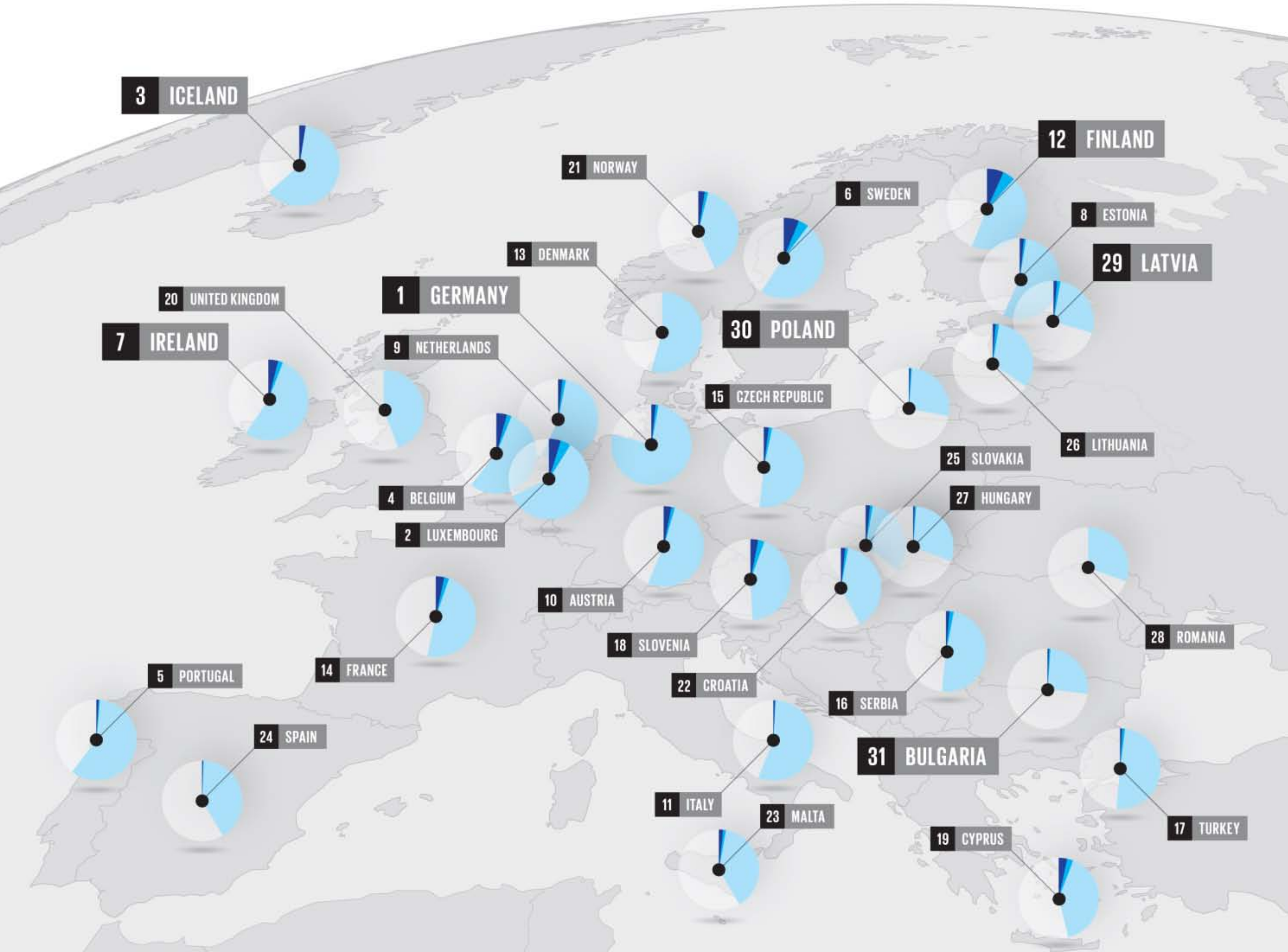
For more information about the Division of Automatic Control visit www.control.isy.liu.se or contact Professor Svante Gunnarsson, svante.gunnarsson@liu.se.



DATAFLOW_

INNOVATION EUROPE
GERMAN BUSINESSES LEAD THE PACK

As the global financial crisis roiled Europe, who was still investing in the future? From 2008 through 2010, the European Union's EuroStat office conducted a survey to gauge commercial innovation. The numbers have now been crunched to create a continental leaderboard of business creativity (except for Greece, for which no data was available), with innovation defined as the creation of "new or significantly improved goods or services or the implementation of new or significantly improved processes, logistics, or distribution methods." The survey also captured the rate of collaboration on innovative activities with partners in the United States or China and India. **—STEPHEN CASS**



KEY

ENTERPRISES WITH INNOVATION ACTIVITY

ENTERPRISES INNOVATING WITH A PARTNER IN INDIA OR CHINA*

ENTERPRISES INNOVATING WITH A PARTNER IN THE UNITED STATES*

Germany

A national economy that weathered the financial crisis better than most left German business in a good position to invest in research and development.

Iceland, Ireland

Both countries were among the hardest hit by the financial crisis, but Icelandic and Irish enterprises still managed to achieve some of the highest rates of innovation.

Finland

The Finns are the most active in reaching beyond Europe, with both the highest proportion of companies working with U.S. partners and the highest proportion working with Asian partners.

Eastern Europe

The lowest rates of enterprises with innovation are to be found in the East, with the former communist countries of Bulgaria, Latvia, and Poland coming in at the bottom.

*Some companies may be innovating with a partner in both the United States and India or China.

SOURCE: THE COMMUNITY INNOVATION SURVEY 2010, EUROSTAT

INFOGRAPHIC BY Carl DeTorres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