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Special Report
TRADING WATER FOR WATTS
THE HARD CHOICES START NOW

Lessons From
AUSTRALIA'S KILLER DROUGHT

URANIUM FROM SEAWEED
and 4 Other Crazy Schemes

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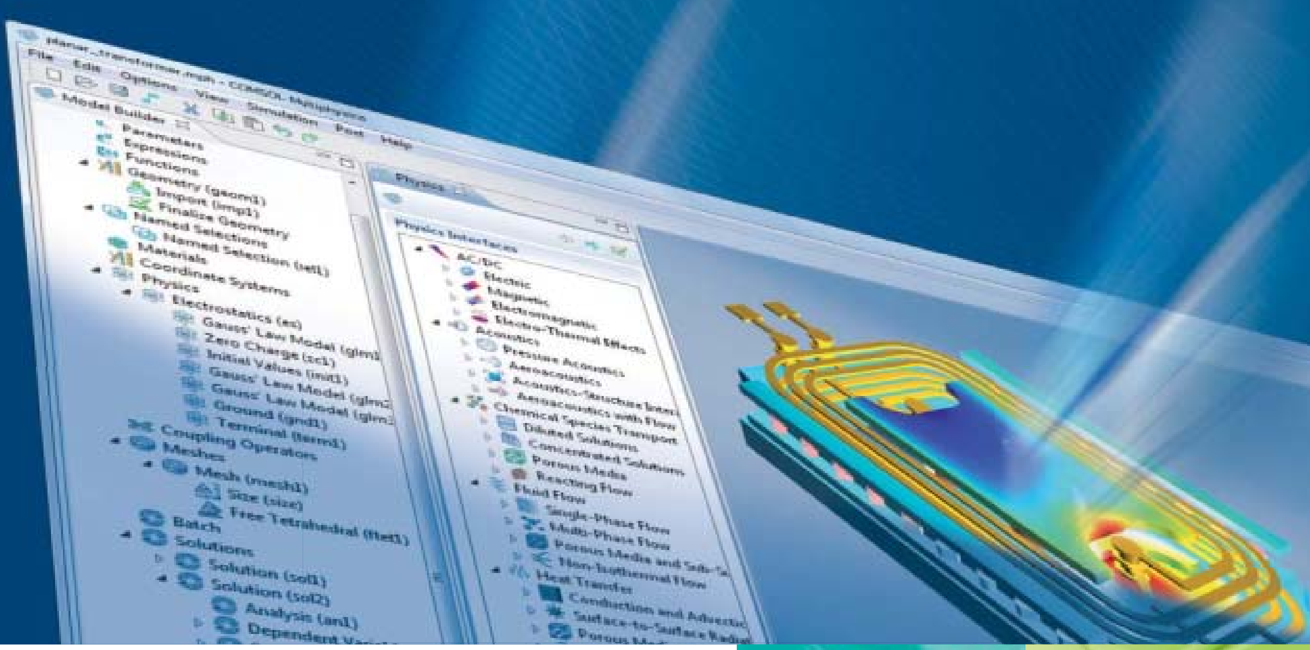

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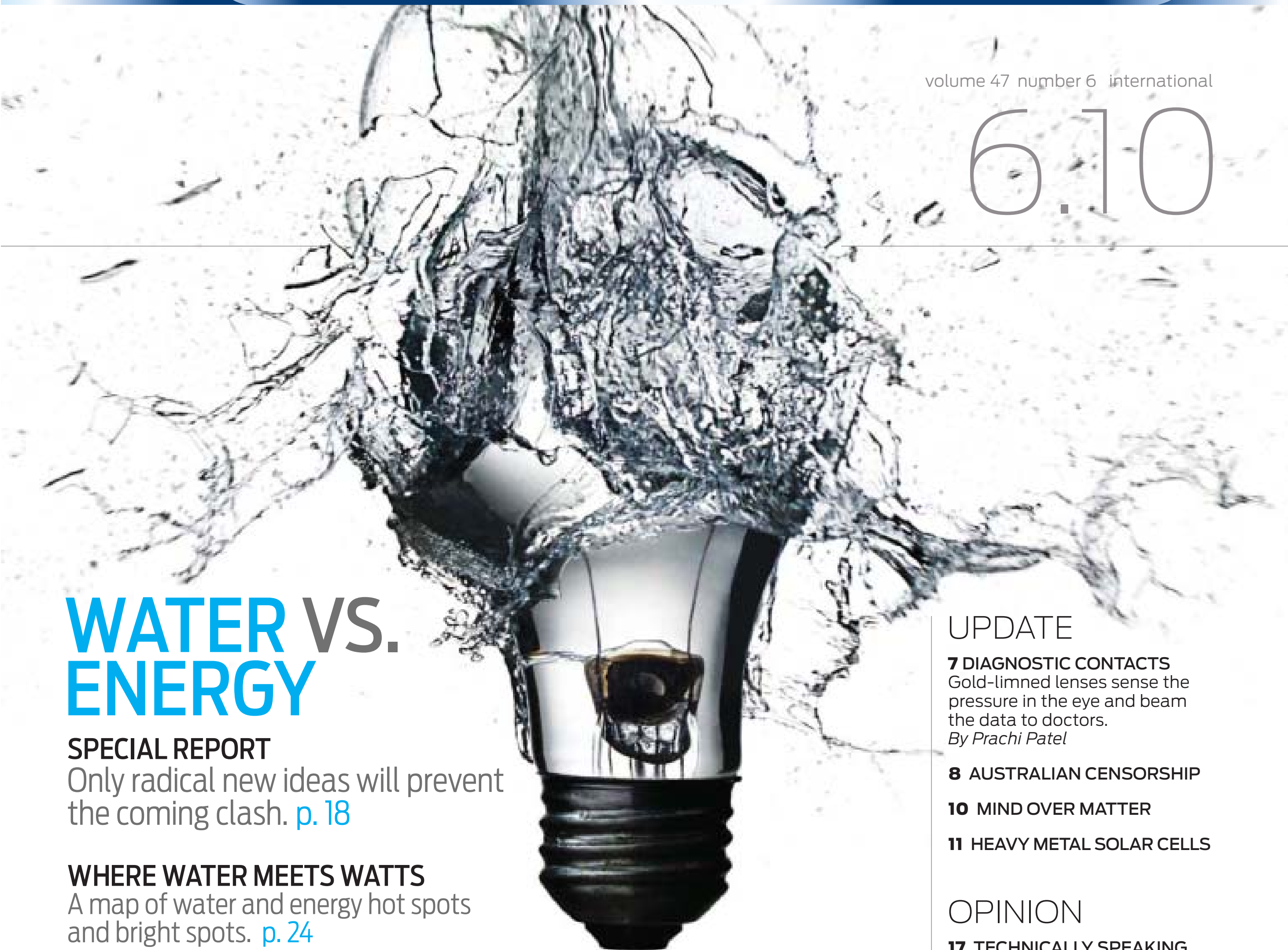
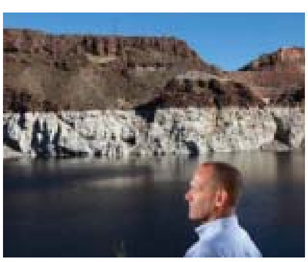


WATER VS. ENERGY

SPECIAL REPORT

1. THIRSTY MACHINES



2. UNEASY HARVEST

3. TINY TEST BEDS

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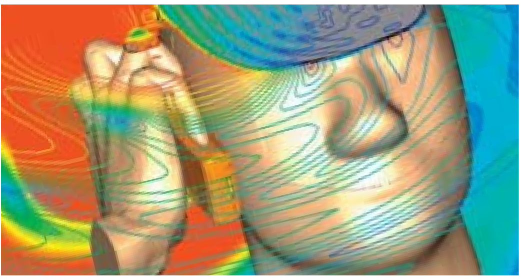
COVER AND THIS PAGE, TOP: DAN SAELINGER; BOTTOM, FROM LEFT: GREGG SEGAL; BRAD DeCECCO; DARREN SOH



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On 3 and 4 June, you can join thousands of IEEE members online in a massively multiplayer forecasting experiment cosponsored by *IEEE Spectrum* and the Institute for the Future. Whether you have 5 hours or 5 minutes, you can help explore the future at the intersection of water and energy. Join this unprecedented thought experiment alone or in teams. Win forecasting points and maybe even transform the way the world looks at water and energy. Spotlight unexpected challenges that others may be missing and help reveal solutions that only the collective brainpower of the IEEE can uncover. Make your ideas count. For details, go to http://spectrum.ieee.org/signtific.

TOP: ISTOCKPHOTO
DIGITAL MANIPULATION: RANDI SILBERMAN KLETT
RIGHT: BARBARA COLOMBO; FAR RIGHT: GRANT OAKES

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IEEE ANNUAL ELECTION

It's time to get to know the candidates for 2011 IEEE President-elect: Gordon W. Day and Joseph V. Lillie. Learn about their personal sides, including what they were like in college,

Gordon W. Day

Joseph V. Lillie

what they do in their free time, and who their role models are.

FASTER ACCESS TO RESEARCH

In the past few years, several online-only journals have been launched in IEEE Xplore, and others are posting their articles in the digital library before they appear in print.

NEW STUDENT BENEFITS

A recent collaboration between IEEE and Microsoft gives student members such benefits as free development software and training.

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back story

Lightbulb Liquidators

So how *do* you fill a lightbulb with water and blast it to smithereens? That was the question on Dan Saelinger's mind when we asked him to produce this month's cover image.

At the photo shoot, Saelinger [center] and his assistants, Greg Krauss [left] and Jeff Elkins, propped up black foam boards to build a set for the lightbulb, which was perched on a thin Plexiglas pedestal. Saelinger mounted a high-caliber pellet gun on a stand and pointed the barrel through a hole in the foam wall.

Goggles went on. "All right, we're loaded," said Krauss, who was manning the gun. Elkins squatted down to flip on the sound trigger, a timer they'd set up to activate the lights. He silently gave a thumbs-up to Saelinger, who turned to his camera, the lens of which also poked through the foam, and propped open the lens's shutter.

Krauss fired, and the sharp "pop" triggered the timer. Five milliseconds later, the studio filled with light just long enough to show glass and water splaying outward at lightning speed. The room went black, and Saelinger walked over to his laptop to examine the result. "We had to work out a very exact way to do this," Saelinger later explains. "We're talking a millisecond's difference to catch it, and every explosion is different."

In a separate room, two stylists were drilling tiny holes into lightbulb after lightbulb. Using a pipette, they squirted water into the glass before plugging the hole with a mix of wax and glue. By the end of the afternoon, glass shards and pellets covered the studio floor, slick from all the water that had been flying around.

Weeks later, Saelinger was still discovering slivers of the 150 lightbulbs they'd shattered in odd corners of his studio. But no regrets here. "Every time we'd shoot and fire one through, we'd smile or laugh—it never got old." ❑

RANDI SILBERMAN KLETT

CITING ARTICLES IN IEEE SPECTRUM

IEEE Spectrum publishes two editions. In the international edition, the abbreviation INT appears at the foot of each page. The North American edition is identified with the letters NA. Both have the same editorial content, but because of differences in advertising, page numbers may differ. In citations, you should include the issue designation. For example, Technically Speaking is in *IEEE Spectrum,* Vol. 47, no. 6 (INT), June 2010, p. 17, or in *IEEE Spectrum*, Vol. 47, no. 6 (NA), June 2010, p. 21.

336 Volts of Green Engineering

MEASURE IT – FIX IT

Developing a commercially viable fuel cell vehicle has been a significant challenge because of the considerable expense of designing and testing each new concept. With NI LabVIEW graphical programming and NI CompactRIO hardware, Ford quickly prototyped fuel cell control unit iterations, resulting in the world's first fuel cell plug-in hybrid.

MEASURE IT

Acquire Acquire and measure data from any sensor or signal

Analyze Analyze and extract information with signal processing

Present Present data with HMIs, Web interfaces, and reports

FIX IT

Design Design optimized control algorithms and systems

Prototype Prototype designs on ready-to-run hardware

Deploy Deploy to the hardware platform you choose

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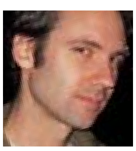
NATIONAL INSTRUMENTS™

contributors

SEPHI BERGERSON, the photographer for "Pumping Punjab Dry" [p. 50], one of several stories in our special report, "Water vs. Energy," was formerly an advertising photographer in Tel Aviv. In 2002 he moved to India, where he added photojournalism and personal projects to his repertoire. He shoots with digital and traditional film cameras, using natural light whenever possible. Bergerson has written and taken photos for two books, *Street Food of India* (2009) and *Horn Please—Truck and Trucking in India* (2010). His third book, *Traditional Weddings in Modern India*, is due out in 2011.

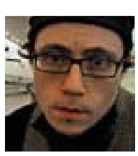


BRAD DeCECCO, who shot the photos for "Life in Drought" [p. 38], followed the story from an Australian farm to a coal mine and then to urban Brisbane. He found himself in the midst of a flock of sheep just days after several had given birth, got as close as he could to the active parts of the mine, and learned to drive on the left side of the road. DeCecco started taking pictures in high school just "to impress a girl," but photography quickly consumed him, and he hasn't wanted to do much else since.

PETER FAIRLEY, an *IEEE Spectrum* contributing editor, writes in "Heavy Metal Power" [p. 11] about how solar technology may soon be cheap enough to compete with fossil fuels and that First Solar, a pioneer in cadmium telluride photovoltaic modules, is now facing a challenge from General Electric for a place in the sun. Fairley splits his time between British Columbia and Paris.

PAUL McFEDRIES has been writing *Spectrum*'s Technically Speaking column since 2002. In "The Rise of Peep Culture" [p. 17], he categorizes, with some incredulity, the exhibitionists who don't seem to appreciate the meaning of "too much information." McFedries, a multiplatform kind of guy, recently wrote user's guides for both Microsoft Windows 7 and Mac OS X Snow Leopard. His Web site, Word Spy, tracks emerging words and phrases.

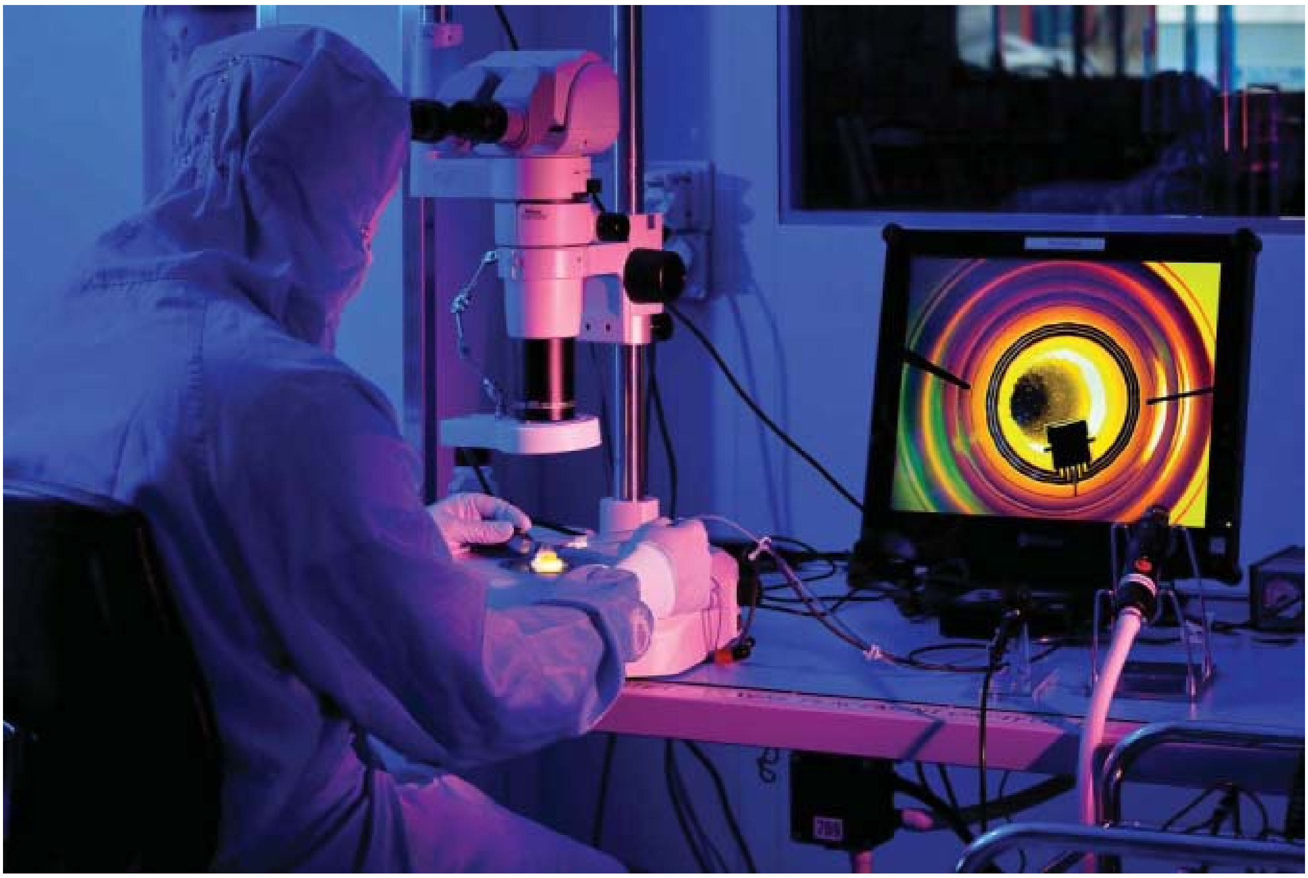
SEEMA SINGH, a *Spectrum* contributing editor, has been writing about science and technology for nearly 14 years from Bangalore, India. Five years ago, she researched water and its associated inequities and inefficiencies under a MacArthur grant, and she recently revisited the issues for "Pumping Punjab Dry" [p. 50]. Not much has changed, she found, and her subjects were only too eager to talk. "Most farmers I interviewed felt I could instantly take their message to the government," she says.



ANDREW ZBIHLYJ created the maps for "Water vs. Energy" [p. 18]. Although his work usually focuses on people and "definite objects," he enjoyed the challenge of applying his style—combining stark black and white with flowing color—to the landscape designs. He struck a balance between photography and abstract art, starting with satellite photos of the regions, then building large-scale, high-resolution digital maps, and finally "reinterpreting" the maps by hand with ink and line drawings "to make all the elements gel."

CLOCKWISE FROM TOP LEFT: SEPHI BERGERSON; KAREN HAMMOND; HEMANT MISHRA; ANDREW ZBIHLYJ; RANDI SILBERMAN KLETT; BRAD DeCECCO

update



BULL'S-EYE: The concentric rings of a diagnostic contact lens begin with a circular antenna, which receives RF energy from an external transmitter. This energy powers a microprocessor. Another ring stretches as the eyeball flexes, measuring changes in intraocular pressure.
PHOTO: SENSIMED

Diagnostic Contacts

A contact lens that tracks ocular pressure may help treat glaucoma

There is no cure for glaucoma, which affects around 65 million people worldwide and is the second-most common cause of blindness in developed countries. Even with vigilant monitoring, drugs, and surgery, some patients go on to lose their sight. For these patients, hope could come in the form of a gold-ringed contact lens.

The lens, made by Swiss medical-device company Sensimed, picks up slight changes in fluid pressure inside the eye and beams the data to a palm-size recorder. It's been approved for use in Europe and is being tried on about 100 glaucoma patients in six research centers in Austria, Germany, and Switzerland.

Sensimed CEO Jean-Marc Wismer says the lens should make it easy to monitor eye pressure over an entire day. He adds that previous studies on glaucoma patients have shown that in about 80 percent of cases, such monitoring allows doctors to improve treatment, either by refining the patient's drug regimen or recommending surgery earlier.

"This device has the potential to revolutionize glaucoma care," says Kaweh Mansouri, an ophthalmologist who has used the system on 15 patients at the University Hospitals of Geneva. He adds that it could do as much for glaucoma patients as home-based 24-hour blood-sugar monitoring has done for diabetes patients.

Tracking internal eyeball pressure is critical to predicting the outcome of glaucoma. High pressure from excessive fluid buildup inside the eye is thought to be the main reason glaucoma causes vision loss. Blindness

update

seems to result when a buildup of fluid in the eye raises the pressure enough to damage the optic nerve. Eye doctors measure intraocular pressure periodically with an instrument called a tonometer. But these occasional in-office tests can easily miss the full picture.

"There are some people that have glaucoma but don't have high pressure, or maybe they have high pressure but not when they come in, and

HYPNOTIC POWER: Behold these reflections in a golden eye.
PHOTO: SENSIMED

we do that instantaneous measure," says Charles Leahy, an optometrist at the Massachusetts Eye & Ear Infirmary. And "you don't know if their pressure spikes at night." The new contact lens monitoring system provides more meaningful data, he says.

Patients have a circular antenna taped around the eye and connected to a battery-powered portable recorder that can be carried in a pocket or worn around the neck. The antenna transmits radio frequency energy to an ultrathin gold ring—itself an antenna—that's on the lens. The RF energy powers a tiny chip embedded in the lens. Also on the lens is a thin platinum ring that stretches, changing its resistance, as the eyeball inflates slightly from its internal pressure. The microprocessor measures this change and sends the data back to the recorder.

The setup might sound cumbersome to wear and sleep with for 24 hours, but so far the roughly hundred patients who have tried the system wore it eagerly. These are people "who are getting blind despite treatment; they're extremely motivated to stop losing vision," Wismer says. And the alternative monitoring scheme is rather unpleasant—spending the night in a sleep lab and being awakened every few hours for measurement.

The lens is already being distributed in Europe, and Sensimed hopes to get regulatory approval in the United States by late 2011. For now, the lens is being used to monitor only diagnosed patients, but Wismer says it could someday be part of routine diagnostic testing of people who have a family history of the disease or show abnormal pressure readings. Drug developers could also use the system to evaluate the effectiveness of new medicines.

—Prachi Patel

Censorship Down Under

Australia's proposed Internet restrictions would be more sweeping than any yet seen in a democratic country

The Australian government plans to introduce a law establishing online censorship so broad that some experts compare it to that of Saudi Arabia.

Communications minister Stephen Conroy says the new regulations are needed to protect the nation from child pornography and inadvertent exposure to other undesirable material. The government also argues the need to bring the Internet in line with other communications media, such as DVDs and TV. Opponents—including tech giants like Google, Microsoft, and Yahoo, as well as local organizations like the Australian Federation of AIDS Organisations and Electronic Frontiers Australia—have responded that the scope of the content to be filtered is too broad and that the law will prove ineffective.

For the technology industry, more is at stake than just free speech: Restrictions on the flow of information threaten the commercial interests of Internet companies. But this isn't simply a story of corporate greed. In a twist on the traditional history of capitalism, commercial interests

10 010 MEGAWATTS The amount of wind capacity installed in the United States last year, a record addition that raises the total above 35 000 MW, enough to light some 10 million homes, according to the American Wind Energy Association.

SURF SERFS: Aussies surf the Web freely, while they still can.
PHOTO: ROB GRIFFITH/AP PHOTO

on the Internet are often closely entwined with those of the public.

While no one would defend child pornography, many would argue that they have a right to buy a cheaper airline ticket offered on an overseas server and to read material that's freely available online, even if it lacks a copyright in their own country. And banning content is a slippery slope.

"To police the Internet and maintain freedom of speech is very, very hard," says Rob Faris, research director of Harvard's Berkman Center for Internet & Society. What is happening in Australia, he says, "highlights the dilemma."

The proposed law, which was announced in December, will take the form of a legislative amendment to Australia's Broadcasting Services Act. It will require all Internet service providers to block material hosted on overseas servers that has been rated "Refused Classification" by the country's Classification Board. The board rates material, such as movies and computer games, based on offensive language, nudity, sex, and violence.

Although the board would not rate the entire Internet, a blacklist of Web sites would be developed based on public complaints to the Australian Communications and Media Authority (ACMA). Regulators at ACMA will refer the site to the Classification Board.

Critics say that applying the existing classification scheme to the Internet could lead to the blocking of hundreds of thousands of sites, including many whose content is purely educational. Mark McLelland, an associate professor of sociology at the University of Wollongong, in New South Wales, notes that millions of players of online games, such as *Second Life* or *World of Warcraft*, communicate in real time, via text or even voice. "Does the whole game become blacklisted if someone were to make a complaint to the ACMA about the 'unsuitable' content generated in these communicative spaces?" he asks. Also, the blacklist would be secret, so a site that is unfairly blocked may have no way to appeal that decision.

However, Senator Scott Ludlam, a member of the Australian Greens, says the larger issue is that the filtering system will fail. "It simply will not work," he says. "It will be trivial to circumvent."

There are a number of technical ways to get around filtering, including using a virtual private network, which provides a secure channel between a computer and a Web site; proxy Web sites, which display banned material within them; and anonymizing software, such as JonDo or Tor.

It may seem strange that Australia should join such Internet-censoring nations as China, Iran, and Saudi Arabia. Yet censorship has already gotten a start in democratic countries: Many ISPs in Canada, Denmark, Finland, Norway, Sweden, and the United Kingdom voluntarily filter Web sites. Mostly, these ISPs block access to child pornography sites.

The Australian law would go further, constituting "the most extreme filtering by any democratic country," says Harvard's Faris, a contributor to the OpenNet Initiative. "Australia will be closer to Saudi Arabia, where most of the filters are directed at socially sensitive material," he says.

Recent polls show that about 90 percent of Australians are concerned about the proposed law. In February, a group calling itself Anonymous launched a denial-of-service attack on government Web sites. More recently, free-speech activists have organized rallies, picnics, and petition drives and set up a dedicated YouTube channel. Colin Jacobs of Electronic Frontiers Australia says it is unclear whether the government will have enough votes to pass the law this summer.

"The proposed law sets a very dangerous global precedent," says Gwen Hinze, international director of the Electronic Frontier Foundation, one of the most venerable defenders of Internet freedom. "Many repressive governments are watching what Australia is proposing, and they are likely to point to it to justify what they are doing to exert control over their countries' own Internet."

—Elise Ackerman

news briefs

Teaching a Virus to Photosynthesize
Researchers at MIT have found a way to get a virus to mimic some of the actions of photosynthesis. When added to a container of pigment and a catalyst, the virus arranges itself and the other molecules in a structure that can share in the energy that the pigment absorbs from sunlight. The scientists plan to create chemical systems that can use that energy to split water directly into hydrogen and oxygen, which can be burned later on to make electricity.
PHOTO: DOMINICK REUTER

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

1 MILLION The number of iPads sold as of 2 May, of which 300 000 were the just-released 3G unit, according to Apple. With a 16-gigabyte flash drive, the 3G iPad costs US $629, compared to $499 for the Wi-Fi–only model.

update

tech in sight

Mammalian Mind Over Matter

As brain-machine interfaces become more advanced, so do the devices they can control

Researchers have long been working to put the brain in direct communication with machines. Recent demonstrations have seen animals and humans controlling ever more complex devices—advanced robotic arms and even prosthetic limbs that can provide tactile sensations. Here's how a monkey, a rat, and a man were able to move matter with their minds.

University of Pittsburgh
PHOTO: ANDREW SCHWARTZ/UNIVERSITY OF PITTSBURGH

University of Florida
PHOTO: JUSTIN SANCHEZ/UNIVERSITY OF FLORIDA

Universities in Pisa and Rome, Italy
PHOTO: UNIVERSITÀ CAMPUS BIO-MEDICO DI ROMA

MONKEY DO

At the University of Pittsburgh's MotorLab, Andrew Schwartz and his colleagues have taught a monkey to control a robotic manipulator with 7 degrees of freedom. The monkey received two brain implants, one in the hand area and another in the arm area of its motor cortex. When the researchers place a knob at arbitrary positions in front of the animal, it can maneuver the robotic arm to grasp the knob. Then the monkey can precisely turn the knob by controlling the arm's mechanical wrist. It's probably the most complex machine a monkey has ever mastered with its thoughts alone.

ROBORAT

Justin Sanchez and his colleagues at the University of Florida's Neuroprosthetics Research Group, in Gainesville, are developing a new class of software decoders to translate brain activity into control signals for prosthetic devices. Although other brain-machine interfaces are static, these decoders adapt their parameters as the brain itself does when learning a new task. Using them, graduate student Babak Mahmoudi showed how a rat could learn to control a robotic gripper that bears no resemblance to its own limbs. Essentially, the rat used brain activity to perform an action unrelated to any movement it could make on its own, as if the decoder were an extension of the rat's brain.

I, ANDROID

A group of scientists at the Scuola Superiore Sant'Anna di Pisa and the Università Campus Bio-Medico di Roma, in Italy, have demonstrated how an amputee can control a robotic hand after having electrodes surgically implanted on two different nerves of his arm. The electrodes captured signals originating in the man's brain, allowing him to wiggle the mechanical fingers and hold objects. What's more, the nerve-machine interface was bidirectional: The robotic hand had touch sensors that could send electrical signals back to the nerves, and the man's brain translated them into a touch felt on a hand lost years before.

—Erico Guizzo

PANEL LEADER: The First Solar factory in Frankfurt (Oder), Germany.
PHOTO: FIRST SOLAR

Heavy Metal Power

General Electric hopes to rock the solar world with cadmium-based solar cells

LIKE THE mask that conceals a superhero's dark secret, the glass and plastic sheets encapsulating the world's fastest-growing solar panel design conceal an unlikely environmental hero: cadmium. Now this toxic heavy metal, together with tellurium, aims to make solar power cheap enough to compete with fossil fuels, perhaps within a decade. The latest sign of the technology's rising fortunes is the decision by General Electric to enter the business next year.

The design is part of a broader technology known as thin-film photovoltaics. Its main advantage is that the layers in the device—which actually convert sunlight to electricity—can be made far more cheaply than by using the monocrystalline silicon of conventional cells. However, thin-film semiconductors are harder to make in quantity, and they convert electricity less efficiently.

Then came First Solar, based in Tempe, Ariz., which began mass-producing cadmium telluride modules in 2004 and last year produced over 1 gigawatt's worth, making it the solar market leader [see "First Solar: Quest for the $1 Watt," *IEEE Spectrum*, August 2008]. First Solar drove the price of CdTe down and its efficiency up, to a stable 11 percent. Although that still fell short of the 18 to 21 percent efficiency of conventional silicon, the cost per watt was about 50 cents to $1 cheaper—good enough to score big when growing subsidies from European governments drove module demand beyond what silicon manufacturers could supply in 2008.

CdTe now accounts for three-quarters of the 4.8-GW capacity that utility-scale solar installations are planning and for which they have specified a technology, according to Emerging Energy Research, a consultancy in Cambridge, Mass. And this summer First Solar plans to start building the world's largest solar power plant: a 2-GW array in Ordos, a center for energy development in China's Inner Mongolia territory.

Clearly, this is the time for the big boys to enter the game, if they hope to play in it at all. GE says it will challenge First Solar in the utility market next year with a design that boasts 16.5 percent efficiency in small cells—a record for CdTe technology. Part of GE's trick is to rely more heavily on cadmium than previous designs have been able to manage.

In a conventional CdTe cell, the layers are deposited on a glass sheet, which is flipped over to face the sun. First comes a transparent metal-oxide layer that will form the cell's top electrode. Next up are the layers—cadmium sulfide, followed by cadmium telluride—that form the *p*- and *n*-type semiconductors, whose junction forms the cell's active, energy-converting region. A coating of silver forms the bottom electrode.

In the GE design, the top electrode consists not of a layer of tin oxide, as in conventional cells, but of a relatively thick layer made of a cadmium-tin oxide called cadmium stannate, plus a thinner layer of zinc-tin oxide. The electrode is therefore more conductive and more transparent.

Observers say GE and other would-be CdTe entrants will need to improve their cells' performance. First Solar has driven its module cost per watt down 30 percent over the past two years, and it's planning to cut costs a further 26 to 39 percent by 2014.

Suppliers of conventional silicon cells, meanwhile, are closing the gap. Ken Zweibel, who directs George Washington University's Solar Institute, estimates that the cost advantage of finished systems using First Solar's CdTe modules has slipped to about $0.25 per watt.

In the world of green energy, even superheroes must compete.

—PETER FAIRLEY

news briefs

The Logic Behind the Memristor

The team at HP Labs that two years ago unveiled the first memristor—the fourth basic element of electrical circuitry—has now shown that this device can handle either data storage or logical computation, depending on the amount and duration of the current sent through it. The memristor can't do all jobs as well as the transistor, the researchers note, but it's clearly better at certain logical operations, notably material implication, the function that states, "If *p*, then *q*."

IMAGE: R. STANLEY WILLIAMS

tools & toys

PRÊT-À-PORTER: Moving an app from one smartphone platform to another is no easy feat.
PHOTO: ProOnGo

WRITING SMALL

Too many platforms can spoil the smartphone app

DESKTOP PROGRAMMERS have it easy. Most can still program for 90 percent of the market—Windows—and ignore the Mac OS and all the flavors of Linux. For smartphones, though, things are different. Globally, almost half the 175 million smartphones purchased in 2009 ran the Symbian operating system, and one-fifth were BlackBerries. Most of the rest, about 14 percent, run Windows Mobile, according to a February 2010 report from the IT research analysis firm Gartner. Developers who want to target the large and rapidly growing U.S. market, however, need to consider that the BlackBerry is by far the leading platform there with 42 percent, followed by Apple with 25 percent, while Symbian has less than 5 percent, according to research firm comScore.

Despite the market's heterogeneity, the nexus of smartphones, wireless broadband, and network-based cloud computing constitutes a perfect storm of opportunity for application developers, luring their attention toward the new platforms. "There's a lot of cool things that notebooks or netbooks don't do so well or can't do," says mobile-device-watcher Chris De Herrera. Phones are always on and always connected, pushing e-mail and SMS messages every minute. Smartphones with GPS give turn-by-turn directions, geocode the pictures they take, and search around you for movies, restaurants, and sales at your favorite stores. Smartphones can identify the songs you hear playing and read bar codes and other tags. But all those capabilities can make application development a nightmare.

To be sure, all smartphones have Web browsers. Yet a Web app optimized for one phone may not run well on others—even on other models of the same platform. Processing power, storage, and functionality differ wildly from device to device. You can minimize the differences by processing data back on a server—one of the reasons cloud computing is all the rage. But Dan Turchin, CEO of mobile applications developer Aeroprise, in Mountain View, Calif., warns, "Mobile browsers aren't particularly responsive, and when every click needs to go back to the server, you can wait minutes to process a transaction."

Moreover, browser-based apps can't tap into a smartphone's best features. Mobile application vendor ProOnGo, in Chicago, for example, has a BlackBerry expense-tracking app that lets you photograph a receipt with the phone's camera; the software then reads the text and folds it into your expense report. CEO Phillip Leslie says, "Our deep integration with smartphone cameras wouldn't have been possible with just Web app code, nor would some of the image-processing algorithms we use to manipulate the resulting images."

Still, a native app for the BlackBerry won't run on an iPhone. If you want to reach even 70 percent of the market, you have to program for more than one environment.

So how much work is writing that second version? The short answer is, a lot. "If you intend to develop your application in the native environment of a specific device, 'moving' it to another platform is synonymous with rewriting it," says Brandon Trebitowski, who heads software development at ELC Mobile, the mobile development arm of ELC Technologies. "Most mobile devices support different programming languages and have entirely different software development kits."

"To do multiple versions, there was nothing we could borrow," reports Ray Bernaz, founder and CEO of Socialibrium, whose products—developed first for the iPhone—help users manage their social networks. "We had to redo the entire user interface and back end for the BlackBerry. There was no code we could reuse, as the iPhone and BlackBerry use different programming languages"—Objective C/C++ and Java, respectively.

Of course, new implementations can benefit from previous ones. ProOnGo's Leslie says, "Our Windows Mobile version took us 12 months to write. When you port it, at least the feature set is nailed down. It took only five months to port to BlackBerry, three to iPhone, and two to Android. The one place where we got some good portability is BlackBerry and Android, because they're both Java-based."

So which platform comes first? With nearly half the market, it would seem an easy choice—BlackBerry, which excels in business-related applications, such as time and expense trackers, business-card readers, apps for creating and distributing forms, and De Herrera's favorite, an HP 12c calculator emulator. "CPAs love this," he says, because it can make interest calculations not easily done in Excel.

Choosing among the other platforms isn't as easy. The iPhone has the next-largest market, but according to Chris Chodnicki, chief technology officer of Internet marketing and technology firm R2integrated, in Baltimore, "it is the hardest to program in terms of following Apple's guidelines and protocols." He says that the new Windows Mobile 7 "would be the easiest to program due to its full integration with Microsoft's Visual Studio integrated development environment."

Chodnicki cautions that staying current can also be a challenge. "The platforms change rapidly," he says, "and knowing more than two mobile platform languages at an expert level is a herculean exercise."

Cross-platform development is hardly new, of course, and one classic industry solution—cross-platform tools—has come to smartphones. Among these tools are Appcelerator Titanium, Phonegap, QuickConnect, Rhomobile (pronounced "roamable" not "row-mobile"), and WidgitPad. Most use a mix of HTML, CSS, and JavaScript, plus some native "wrapper" code for accessing hardware features like GPS, a camera, or an accelerometer.

Rhomobile's software, which can be used to create native apps for iPhone, Windows Mobile, BlackBerry, Symbian, and Android, works so well that Aeroprise, which already has its own development platform, chose it to quickly create smartphone versions of one of its desktop programs. "We had to support not just BlackBerry but also iPhone, Symbian, Android, and Windows Mobile," says Aeroprise CEO Turchin, who sits on the Rhomobile board.

Vidal Graupera, an independent software developer, says, "In Rhomobile, you write using HTML, CSS, JavaScript, and Ruby, which is a very developer-friendly language." Graupera, who is coauthor of the not-yet-released book *Pro Smartphone Cross-Platform Development* (Apress), says, "You can simply 'push the button' for builds that will run on each environment." Some tweaking will be needed, but the code will run. "It might be a few weeks for each additional platform, to seriously tweak and test," he says.

The testing is particularly important. "When you use a cross-platform tool kit, you're creating a new abstraction on top of old ones," notes Aaron Hillegass, president of Big Nerd Ranch, in Atlanta, and coauthor of *iPhone Programming: The Big Nerd Ranch Guide*. "And the 'leaky abstraction' problem is that with any implementation of an abstraction, the details tend to trickle through."

That means coding to the lowest common denominator, Hillegass says. For example, most platforms don't have multitouch events like the iPhone's pinch-and-spread-fingers way of enlarging a map or an image. "To do a cross-platform tool kit, the first thing you'd do is say, 'You can't have multitouch.' "

Game development, where a developer wants to be able to control every pixel precisely, loses a lot when programming to the lowest common denominator. Fortunately, business apps do not. "Most enterprise applications don't need fine graphic manipulation or interaction with the operating system," says Michael King, a research director at Gartner. "The cross-platform tools are quite good."

Still, there may be deeper benefits to creating native apps with native tools. "An abstraction layer is taking the industry into a dead end," says Hillegass. "To keep innovating, we need a richer environment, not a simpler one." —Daniel Dern

A Programmer's Six-Pack

OS	ANDROID	BLACKBERRY OS	iPHONE OS	PALM WEBOS	SYMBIAN OS	WINDOWS MOBILE
Runs on	Open Handset Alliance	BlackBerry	iPhone, iPad, iPod Touch	Palm Pre, Pixi	ARM processors	Windows Mobile smartphones
Related to	Linux	Unix (BSD and NeXTstep)	Mac OS X	Linux	Psion EPOC	Windows CE
Development languages	Java	Java	Objective C/C++	HTML, CSS, JavaScript; C/C++ (via PDK)	C++, Java, others	Visual C++
IDEs, libraries, frameworks	Android SDK and NDK; ADT plug-in for Eclipse	BlackBerry JDE	iPhone SDK	PDK; WebOS plug-in DK; Project Ares (Web based)		Windows Phone SDK (works with Visual Studio)

KEY: *IDE = integrated development environment; SDK = software development kit; ADT = Android Development Tools; JDE = Java Development Environment; PDK = Palm Development Kit; NDK = native-code development kit*

hands on

COOL IT: With some inexpensive electronics, you can switch things on and off in your house from afar—including the air-conditioning.
PHOTO: DAVID SCHNEIDER

A SMARTER, CHEAPER THERMOSTAT

Controlling home thermostats need not cost a bundle

CALL ME A WIMP. Since moving from New York to North Carolina, I've grown completely dependent on one of engineering's greatest achievements—the air conditioner. For three seasons, the climate of the Southeast is lovely, but summers here are stultifying unless you pump the heat back outdoors.

Unfortunately, cooling the house takes a long time, so come summer, the AC is left on pretty much all the time. Better would be to switch the AC on, remotely, an hour or two before heading home. There's an easy way to do that nowadays, thanks to another great engineering achievement: the Internet. You might use Ecobee's Web-enabled thermostat, but that costs more than US $300. And what if you want to control the lights as well? Such systems exist, but they're even more expensive.

If you don't need a lot of bells and whistles, you can control your central air conditioner and lights without great expense. The system I cobbled together uses a single-board computer of growing popularity: the Arduino. Devoted *IEEE Spectrum* DIYers have seen this name several times in the past year, most notably in "Barbot, the Automated Bartender" (Geek Life, December 2009).

Arduinos come in many flavors. I bought an Arduino Duemilanove ($30). The nifty thing about this board is the way various accessory boards, or shields, can plug right in. Connecting my Arduino to the Internet was as easy as attaching an Ethernet shield ($46) and connecting it to my home router with an RJ-45 cable.

But how to control the air-conditioning? My thermostat, an ancient design, is basically a mercury switch that turns the AC or heat on and off when the bimetallic spiral it's attached to winds or unwinds with the change in temperature. So all I needed to do was to wire a second, Arduino-controlled switch in series with the mercury switch. Then the Arduino could either allow the thermostat to function normally (with the second switch closed) or prevent the air conditioner from being turned on (second switch open).

My home thermostat is located nowhere near my router, so to avoid having to string a cable between them, I decided to control the thermostat by radio, using X10 home-automation hardware. You may know X10 as a system that communicates using signals sent over power lines. But it turns out that some X10 devices can use the airwaves, and the price is right: Just $5 buys an X10 Firecracker radio transmitter. Another $9 gets you an X10 TM751 unit, which the Firecracker can command by radio to switch a plug-in appliance on or off.

By wiring the thermostat's mercury switch in series with a small 5-volt relay, I could enable or disable the air conditioner from another room, using the TM751 to power a wall wart attached to the relay's coil. Interfacing the Arduino with the X10 Firecracker proved easy, because others had posted online code they'd used for this very purpose. Now my Arduino had the means to shut off my air-conditioning system until I commanded it through the Internet to let normal temperature regulation resume.

So far, so good. But what if I didn't want the temperature in the house to climb quite so high? My little Arduino assistant could prevent that, but it needed some way to know how hot the house was. For that, I bought a Dallas Semiconductor 18B20 digital temperature sensor ($4), along with the relay I needed for the second thermostat switch ($2), a wall-wart AC adapter to power the Arduino ($6), and a 5-V wall wart to operate the relay ($6). That brought the total bill of goods to $108—pretty cheap as Internet-connected home-automation systems go.

Assembling the hardware was easy: The Ethernet shield just plugs into the Arduino, three wires connect the Firecracker, and two

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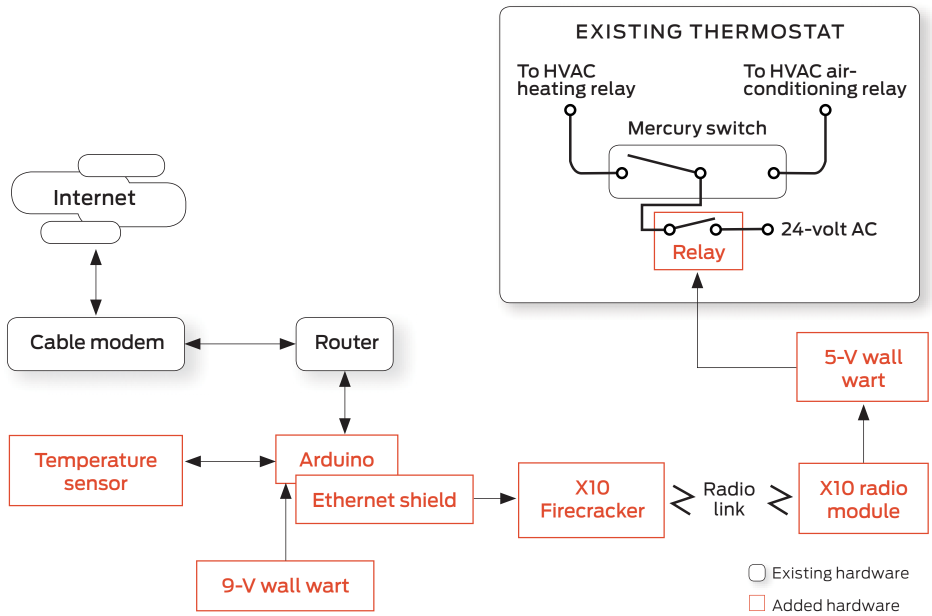


more wires and a 4700-ohm resistor attach the temperature sensor. The only real work involved was writing some code so that I could command the Arduino through the Internet. Fortunately, Arduino's developers have done most of the heavy lifting and written an Ethernet-shield library.

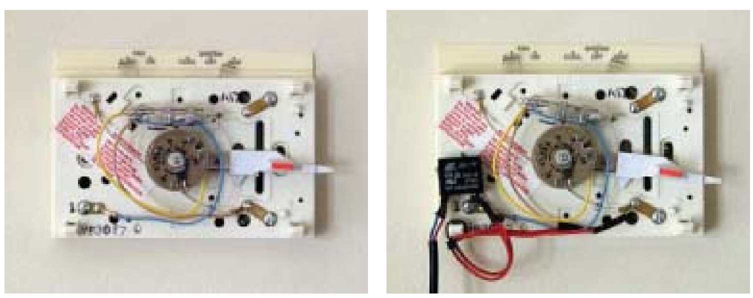
In principle, I could have made my little Arduino board into a Web server, but I worried about using that approach. If the house lost power while I was on vacation, for example, my router might restart with a new IP address from my Internet service provider, rendering me unable to find my Arduino on the Internet. So I instead devised a system based on e-mail.

To control my thermostat, I send an e-mail message to an account I've set up just for this purpose. My ISP gives me several free accounts, so that's easy enough. Other mail servers would have been more difficult to use because they typically require Secure Shell, which the Arduino Ethernet library does not yet support. The Arduino board checks my account every 10 minutes. If it finds a message, it looks for lines that begin with a special sequence of characters, which serve as my secret password, followed by a one- or two-character instruction.

One instruction commands the Arduino to put the temperature regulation into "economy mode" (which sets the target temperature to some uncomfortably high value that won't make the AC run very much). Another commands it to return temperature regulation to its normal mode, controlled by the thermostat's faceplate setting.

Other instructions allow the Arduino to turn on or off lamps that are plugged into additional TM751 units (at $9 each, I'm tempted to purchase a bunch). And lastly, I included an instruction for the Arduino to send me e-mail notification of the status of the house—the current temperature, whether it's in normal or economy mode, and whether any remotely operated lamps are switched to on. Now I can even control these things in my house using an e-mail–capable phone to send and receive short messages.

Although I've not taken pains to tune the feedback loop that controls the house when the Arduino is in economy mode, the air temperature seems just as stable as when the regular thermostat is doing the regulation. And the temperature remains stable even if I disconnect the Ethernet cable. So the little system I've assembled appears reasonably robust,



MISSION CONTROL: A standard thermostat [left] needs a relay added [right] to be controlled through the Internet [see diagram]. *PHOTOS: DAVID SCHNEIDER (2)*

although when my 11-year-old daughter saw the Internet-to-Arduino-to-Firecracker-to-TM751-to-relay control channel, she asked, "Who was that guy who drew pictures of those crazy contraptions?" That would be Rube Goldberg, dear.

If my contraption continues to work well all summer, I'll be tempted to rig it to regulate the heat in winter. But I won't do that until I've gained more confidence that no software or hardware gremlins are lurking. After all, I don't want to end up with a burst pipe if some rare failure condition locks up the Arduino board and leaves the heating completely disabled. Hmmm, maybe I could build another circuit to attach to the...

I can already hear Rube Goldberg chortling with glee.

—David Schneider

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geek life

Filmmaker Roger Nygard interviewed religious leaders, philosophers, cultural icons, and physicists for his documentary *The Nature of Existence*. PHOTO: COURTESY OF ROGER NYGARD

Why Do We Exist?

The answer is coming to a theater near you

FILMMAKER ROGER Nygard—best known for the cult film *Trekkies*—tackled the most existential of questions in his 2009 documentary, *The Nature of Existence*, as we noted in our February 2009 issue, a month before the movie's debut at the Cinequest Film Festival in San Jose, Calif.

Since then, the movie has gone on to win three awards, including Best Documentary Feature at DocuFest Atlanta, and it has been invited to screen at more than a dozen other festivals. It's now scheduled to premiere in theaters in New York (18 June) and Los Angeles (2 July), followed by other theaters across the country.

Nygard asked 170 thinkers on five continents 85 of the toughest questions he could come up with. It was the physicists who waxed the most philosophical, he says—except for one. "Stephen Hawking wouldn't grant an interview," says Nygard. "He said, 'I'm tired of the God question.' " Here are a few musings of those who weren't. —SUSAN KARLIN

Theoretical physicist Sylvester James Gates Jr.
Supersymmetry expert, University of Maryland, College Park, Md.
"In science, whenever we see a diversity of viewpoints, at the end of the day they all become unified because there's one reality. If religion is talking about something that is external to us, then all of them will likely follow a similar path."

Physicist Leonard Susskind
Codiscoverer of string theory, Stanford University
"Sometimes people pray hard for a miracle, and a miracle happens—a miracle meaning something very, very unlikely. But the most unlikely thing of all would be if no unlikely things happened."

Astrophysicist Stanford Woosley
Director, Center for Supernova Research, University of California, Santa Cruz
"The universe evolves. Stars evolve. People evolve. Everything that is alive evolves. We may be the path toward some ultimate intelligence, some ultimate life in the universe that would be virtually indistinguishable from what we call God."

Physicist Steve Biller
Tutorial Fellow in experimental particle physics, Mansfield College, University of Oxford, England
"Particles, in fact, don't exist. Consider, for example, a particle we all know and love, the electron. They're all the same. You know if you produced an electron on the other side of the universe, and you brought it here and compared it with an electron, they're the same. Not in the same way that you pick up two red billiard balls and say, 'These are pretty similar.' We say they're identical. This is because the electron as a separate, distinct entity... doesn't really exist, they are merely bumps in something called 'field,' which is a property of space and time. And if it's true for the fundamental particles in nature, it's true for everything that they make up, including us. And so at some level, we don't exist."

For more information: http://www.thenatureofexistence.com.

technically speaking BY PAUL McFEDRIES

The Rise of Peep Culture

We derive more and more of our entertainment from watching ourselves and others go about our lives. We're going to enter a point where we become quite addicted to being watched.
—writer Hal Niedzviecki, in the *Ottawa Citizen*, 31 January 2009

RICHARD MIA

A FEW YEARS AGO, I was researching the term **camgirl**, used to refer to a girl or young woman who broadcasts live pictures of herself over the Web. I certainly strive to be a disinterested chronicler of new words, but sometimes I just have to shake my head. Why would someone turn her life into a digital peep show? I was tempted to dismiss this as a bizarre hobby for a few teenage exhibitionists caught up in a new technology. But then I read that there were thousands of camgirls out there. And yes, there were plenty of **camboys**, too. Clearly there were larger forces at work.

According to Susan Hopkins, the author of the book *Girl Heroes: The New Force in Popular Culture*, for some kids the constant surveillance of webcams affirms their identities—because they're like, you know, sorta kinda on TV, and only celebrities and important people appear on TV. It's the same impulse that provides a never-ending cast of unembarrassed reality show participants. It's why TV crews never seem to have trouble finding a grief-stricken person to interview after a disaster. The camgirls themselves talk about "artistic expression" and "empowerment," and surely that's true for some. But for most of them the omnipresent eye of the webcam serves only to validate their existence: I cam, therefore I am.

Over the past few years, broadcasting the intimate details of one's life has become mainstream. Many of us are now blogging, Twittering, Facebooking, Flickring, and YouTubing at least some details of our lives. In his book *The Peep Diaries: How We're Learning to Love Watching Ourselves and Our Neighbors*, Hal Niedzviecki calls this **peep culture**. Peep culture is a play on *pop culture*, a phrase that entered the language around 1959 (although the longer form *popular culture* is surprisingly older, with a first citation from 1854, according to the *Oxford English Dictionary*).

One form is the **lifestream**, an online record of a person's daily activities, either via direct video feed or via aggregating the **lifestreamer**'s online content, such as blog posts, social-network updates, and online photos. If this **lifestreaming** is video only, and in particular if the person is using some form of portable camera to broadcast his activities over the Internet 24 hours a day (à la the camgirls), then it's called **lifecasting**, and the stream itself is a **lifecast**.

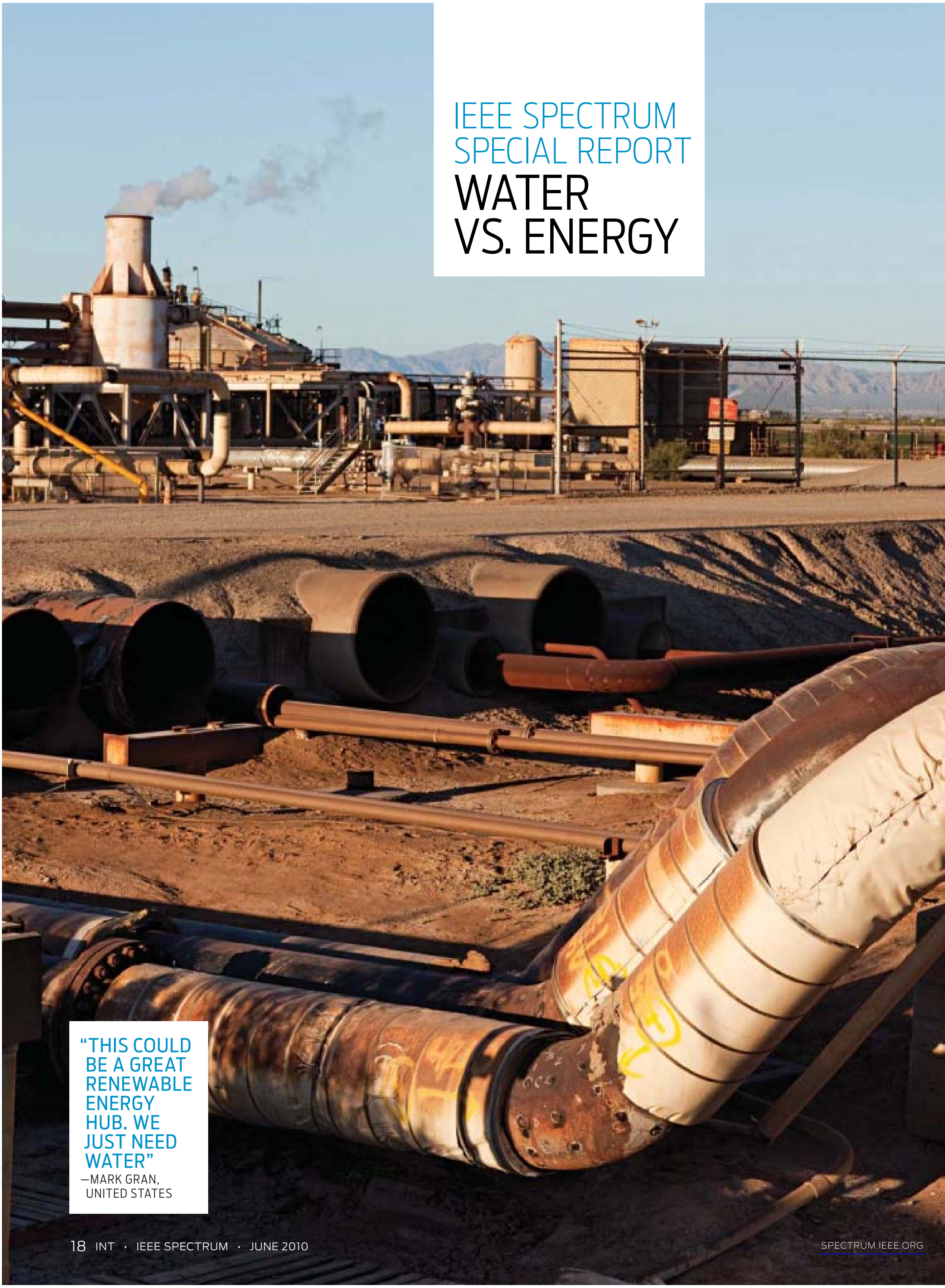
The highbrow version of lifestreaming uses no video and is called **mindcasting**, the practice of posting messages that reflect one's current thoughts, ideas, passions, observations, reading, and other intellectual interests. (This is not to be confused with an earlier form of *mindcasting* that used the term in the more literal sense of attaching a sensor device that broadcasts one's brain waves. No, I'm not sure why anyone would want to do that.) **Mindcasters** are also called **informers** because they post information, as opposed to **meformers**, who post updates that deal mostly with their own activities and feelings. (Just to keep us all confused, some folks also call this lifecasting.)

Other examples of *-casting* include **egocasting**, reading, watching, and listening only to media that reflect one's own tastes or opinions; **Godcasting**, posting an audio feed with a religious message; **slivercasting**, delivering video programming aimed at an extremely small audience; **screencasting**, showing a video feed that consists of a sequence of actions on a computer screen; and, of course, the familiar term *podcasting*.

We may be well on our way to becoming addicted to being watched, but who's doing the watching? If we're all broadcasters now, it's entirely possible that we're beaming our streams, tweets, photos, and status updates to hundreds of "friends" and thousands of "followers" who are too busy broadcasting their own lives to tune in. Peep culture may be the new pop culture, but is this really a two-way mass phenomenon? Maybe most of us have an audience of one: ourselves. ❑

IEEE SPECTRUM SPECIAL REPORT

WATER VS. ENERGY



"THIS COULD BE A GREAT RENEWABLE ENERGY HUB. WE JUST NEED WATER"
—MARK GRAN, UNITED STATES

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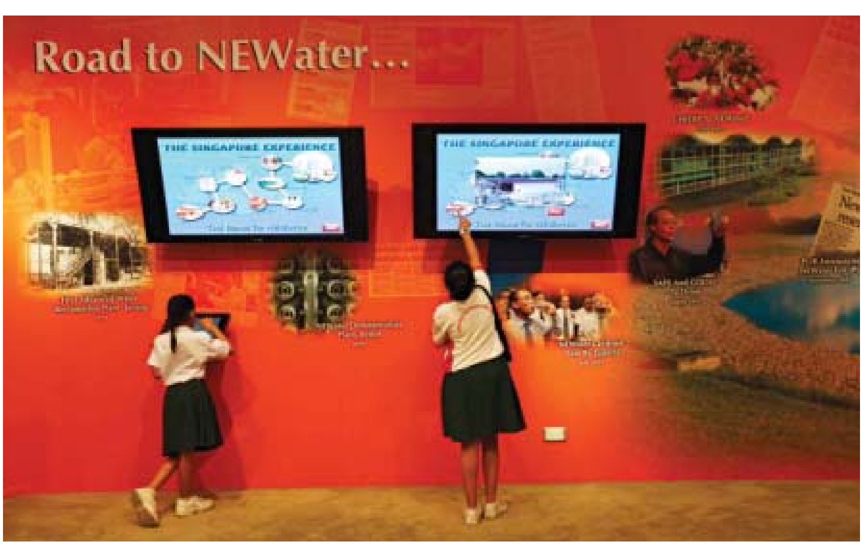
"THERE IS NO LIMIT TO HOW MANY TIMES WATER CAN BE REUSED"
—ASIT BISWAS, SINGAPORE

“WE KNOW IT WILL IMPACT THE NEXT GENERATION OF FARMERS… BUT WE NEED TO FEED AND FEND FOR OUR FAMILIES, TODAY”
—BHAJAN SINGH SIDDHU, INDIA



“IF I CAN ACHIEVE 100 PERCENT RECYCLING, I WOULDN’T EVEN NEED RAIN”
—HARRY SEAH, SINGAPORE

"AFTER COAL, WATER IS NOW OUR LARGEST EXPENSE"
—MICHAEL SINCLAIR, AUSTRALIA

"THEY'RE PLANNING ON AN AVERAGE WATER FLOW IN THE COLORADO THAT EXISTS MAYBE ONCE IN A THOUSAND YEARS"
—TIM BARNETT, UNITED STATES

"UNLESS YOU'RE IN THE POSITION OF THE UTILITIES, YOU CAN'T EVEN FATHOM THE CHANGE THAT'S GOING TO HAPPEN"
—PAUL MICALLEF, MALTA

PREVIOUS PAGES: LEFT: GREGG SEGAL; RIGHT: DARREN SOH. THIS PAGE, CLOCKWISE FROM TOP LEFT: SEPHI BERGERSON; BRAD DeCECCO; JOSHUA ROMERO; GREGG SEGAL; DARREN SOH

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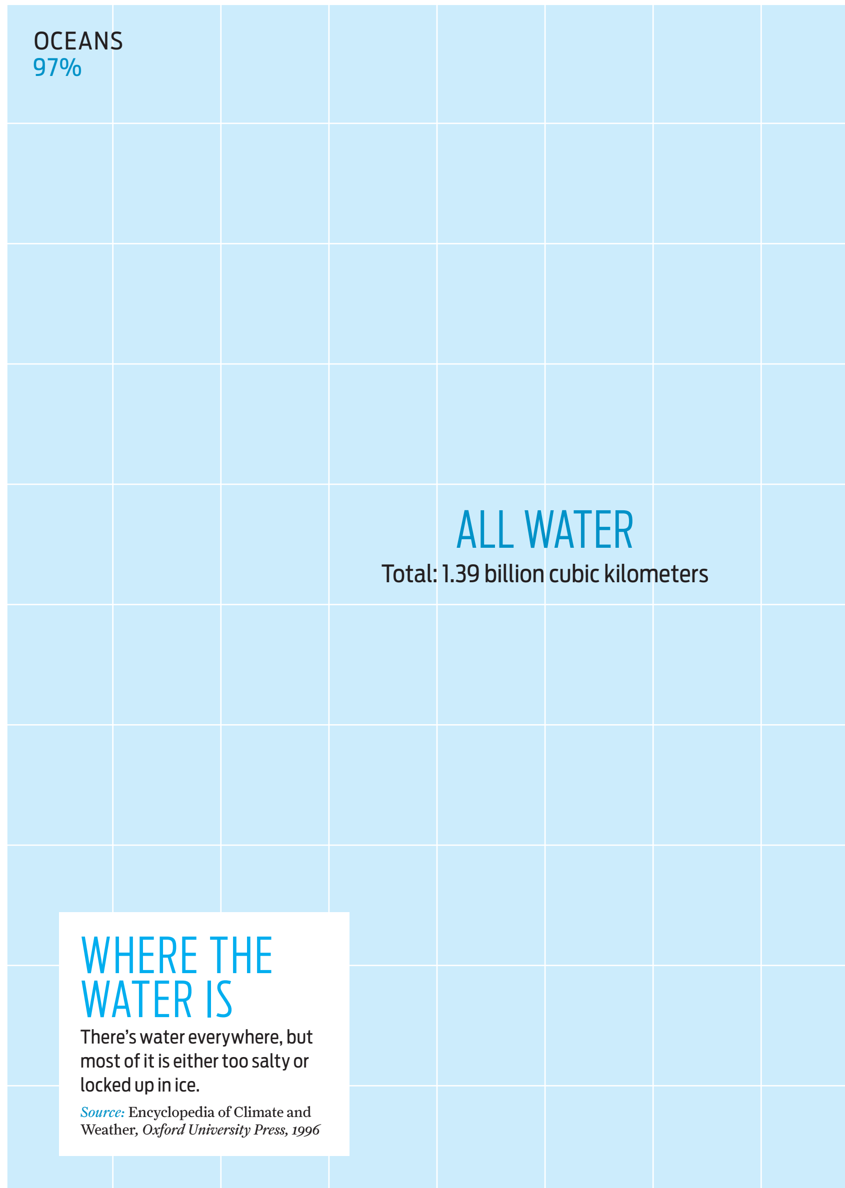
THE COMING CLASH BETWEEN WATER AND ENERGY

Our thirst for water competes with our hunger for energy. Only radical new ideas will get us out of this mess

BY IEEE SPECTRUM STAFF



WHERE THE WATER IS
There's water everywhere, but most of it is either too salty or locked up in ice.
Source: Encyclopedia of Climate and Weather, *Oxford University Press, 1996*

CONSIDER A GIANT SPONGE, WITH limbs and tentacles that reach to the horizon. It dips into distant rivers, it delves for deep waters, it digs ditches to catch the rain—all to slake its insatiable thirst.

Clearly, this is no ordinary sea creature quietly snuffling the currents. We have met this sponge, and it is us. We humans are the thirstiest of creatures, and we've developed a nearly insatiable taste for this simple but delectable arrangement of hydrogen and oxygen atoms. But we need more. So much more.

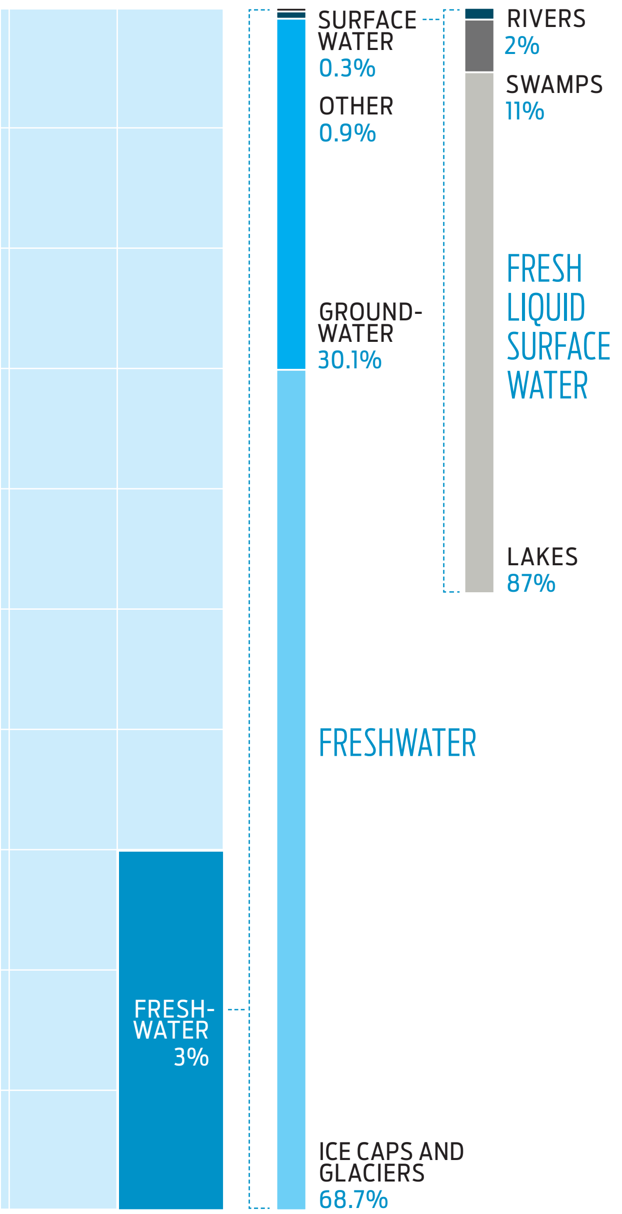
We're not talking about just drinking or bathing. Without water, we'd have practically no energy. Without energy—and therefore cars, planes, laptops, smartphones, and lighting—we wouldn't be doing much.

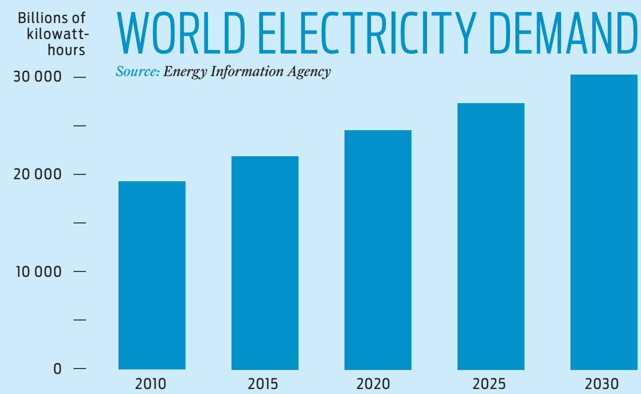
In almost every type of power plant, water is a major hidden cost. Water cools the blistering steam of thermal plants and allows hydroelectric turbines to churn. It brings biofuel crops from the ground and geothermal energy from the depths of the Earth. Our power sources would be impotent without water.

Don't believe us? Plug your iPhone into the wall, and about half a liter of water must flow through kilometers of pipes, pumps, and the heat exchangers of a power plant. That's a lot of money and machinery just so you can get a 6-watt-hour charge for your flashy little phone. Now, add up all the half-liters of water used to generate the roughly 17 billion megawatt-hours that the world will burn through this year. Trust us, it's a *lot* of water. In the United States alone, on just one average day, more than 500 billion liters of freshwater travel through the country's power plants—more than twice what flows through the Nile.

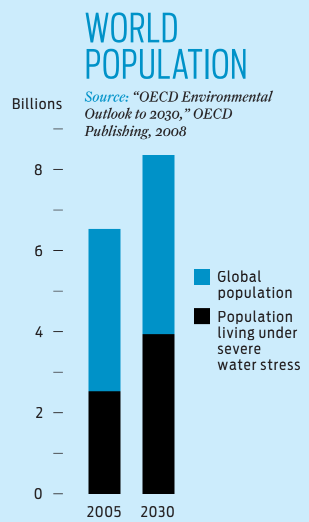
Look at it another way. Robert Osborne, an enterprising water blogger, calculates that a single Google search takes about half a milliliter of water. Just a few drops, really. But the 300 million searches we do a day take 150 000 liters. That's a thousand bathtubs of water to power the data centers that handle the world's idle curiosity. We challenge you to find an activity more trivial than a search engine query.

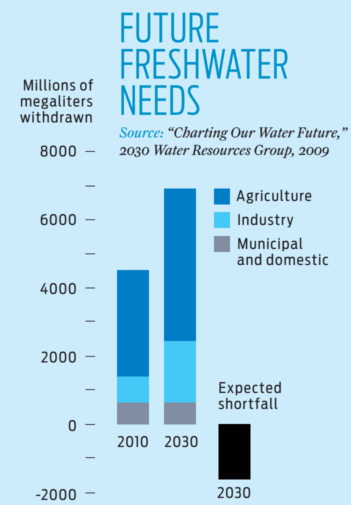
With that much water needed for even the most trifling tasks, the natural question becomes: How does that water





39 PERCENT The fraction of freshwater withdrawn from rivers, lakes, and aquifers in the United States that goes to cooling thermoelectric power plants. Technology is driving power plants to withdraw less water, but they evaporate away more of what they withdraw.





reach those data centers, let alone the world's farms and factories? By using energy, of course.

We burn through entire power plants' worth of output to move water from one river—the Colorado—to bring deserts into bloom. On India's rice paddies, gigawatts of subsidized electricity have fueled an agricultural bonanza but have also induced farmers to pump the groundwater almost down to zero. In China, oversized infrastructure schemes are diverting rivers to the parched industrial cities of the north. On Australian farms, the shift to drip irrigation is saving water but boosting electricity usage.

The era of easy energy and plentiful water is ending; a new way of husbanding these resources must begin. Two islands stand out as compelling test cases. In Malta, a smart grid will monitor both water and electricity to elucidate the connections between the two. And Singaporeans have learned to accept the fact that their urine—treated and cleaned up, of course—is now part of what emerges from the tap.

Are these the kinds of solutions we need to keep the human machine and all its thirsty tentacles sated? We think they're a start. How we plan—or fail—to resolve the competition between water and energy needs will become one of the defining issues of this century. ❑

SPECIAL REPORT ■ WATER VS. ENERGY

WHERE WATER MEETS WATTS

Just having water and energy doesn't protect a place from water and energy conflicts

BY IEEE SPECTRUM STAFF
ILLUSTRATION BY ANDREW ZBIHLYJ

Multimedia
For an expanded interactive map, go online to http://spectrum.ieee.org/watermap.

LEGEND

- Renewable freshwater per capita (millions of liters per person)
- Total primary energy per capita (metric tons of oil equivalent per person)
- Population access to clean water
- Population access to electricity

PROGNOSIS Critical · Grim · Shaky · Fair · Good

UNITED STATES

PROGNOSIS **Grim**

In Nevada, the sinking levels at Lake Mead may cause the Hoover Dam's turbines to drastically cut production—or shut down completely—as early as 2013.

9.3 | 7.75
100% | 100%

BRAZIL

PROGNOSIS **Critical**

A pig-iron producer claims that charcoal from its eucalyptus plantation emits less carbon than would coal, but the fast-growing trees are sucking local waterways dry.

28.5 | 1.23
90% | 98%

FRANCE

PROGNOSIS **Shaky**

France gets most of its electricity from nuclear power plants, many of which are cooled with river water. During heat waves, warmer or depleted rivers can force them to shut down.

2.9 | 4.15
100% | 100%

MALTA

PROGNOSIS **Fair**

Electricity from imported oil powers Malta's three desalination plants. The world's first joint smart grid tracks water and electricity use, with the goal of minimizing theft and curbing consumption.

0.1 | 2.12
100% | 100%

LIBYA

PROGNOSIS **Shaky**

The Great Man Made River Project, begun in 1984, uses Libya's oil to pump nonrenewable groundwater from under the Sahara and deliver it to the cities on the country's northern coast.

0.1 | 2.9
72% | 100%

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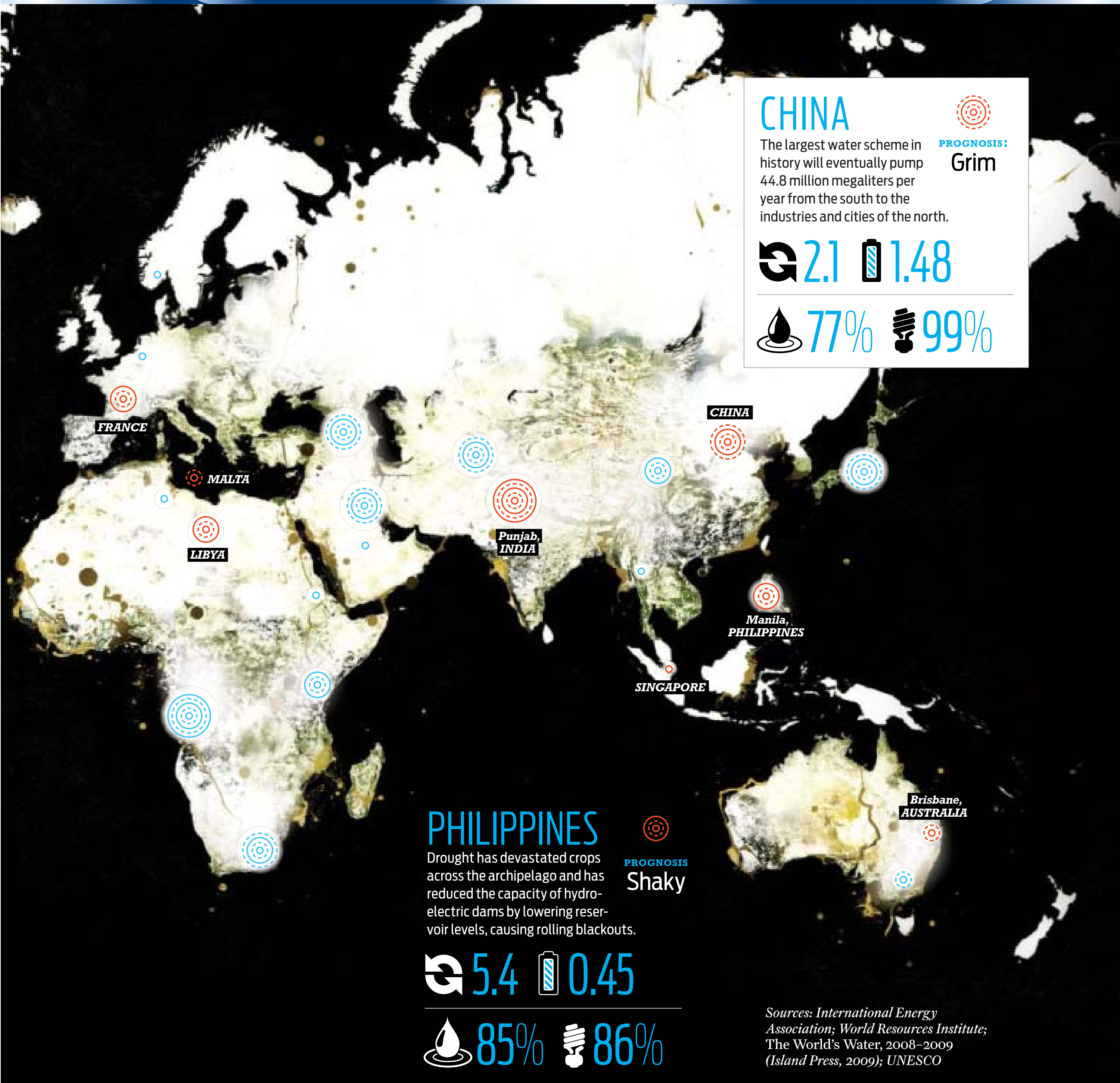

CHINA

PROGNOSIS: Grim

The largest water scheme in history will eventually pump 44.8 million megaliters per year from the south to the industries and cities of the north.

2.1 1.48

77% 99%

PHILIPPINES

PROGNOSIS Shaky

Drought has devastated crops across the archipelago and has reduced the capacity of hydroelectric dams by lowering reservoir levels, causing rolling blackouts.

5.4 0.45

85% 86%

Sources: International Energy Association; World Resources Institute; The World's Water, 2008–2009 *(Island Press, 2009); UNESCO*

INDIA

PROGNOSIS Critical

Free electricity has induced farmers to pump excessive amounts of groundwater, threatening grain production in Punjab, a breadbasket state.

1.1 0.53

86% 65%

SINGAPORE

PROGNOSIS Good

An advanced wastewater treatment scheme cleans up sewage and blends it with rainwater to extend the potable supply on this island, which has minimal water and energy resources of its own.

0.1 5.83

100% 100%

AUSTRALIA

PROGNOSIS Fair

South East Queensland's new AU $9 billion water grid, which includes a desalination plant, three treatment plants, and hundreds of kilometers of pipes, is a hedge against drought, but it is burning many more watts.

23.3 5.87

100% 100%

1

THIRSTY MACHINES

UNITED STATES ▪ CHINA

SPECIAL REPORT ■ WATER VS. ENERGY

THE POWER OF WATER

In the American Southwest, the energy problem is water

BY SALLY ADEE & SAMUEL K. MOORE
PHOTOS BY GREGG SEGAL

MARK GRAN WORKS FOR CALENERGY, A COMPANY THAT HOPES TO EXTRACT THE GEOTHERMAL BOUNTY UNDER THE SALTON SEA. BUT THE COMPANY MAY SEE TROUBLE AS THE WATER RECEDES.

AT THE EDGE OF THE SALTON SEA, Mark Gran surveys the clanking, hissing labyrinth of pipes that curl up from the desert in the distance. In front of him, steam belches up from a geothermal plant's cooling towers, forming perfect puffy clouds that hang against a flawless blue sky.

"We got a lot of pots and pans," he shouts over the noise. Gran is a vice president at CalEnergy Generation, a company that's developing geothermal power in the Imperial Valley, in Southern California.

The 16 geothermal plants that dot the Imperial Valley—10 of which are owned by CalEnergy—are among the first signs of what California hopes will become a renewable-energy boom. Researchers from the U.S. Department of Energy's National Renewable Energy Laboratory estimate that fully exploiting a fault line beneath the Salton Sea would supply an astonishing 2300 megawatts of power, rivaling the output of a big nuclear power plant.

"This could be a great area for a renewable energy hub," says Gran. "We just need water."

Beyond the plant, pipes reach out into the desert to bring water to the plants at the edge of the Salton Sea. For several reasons, the plants can't just take water out of the sea. Instead, they must get their water piped in from miles away. Without that water, this plant wouldn't make a watt. But CalEnergy isn't the first to tap into a water supply that doesn't naturally exist in these arid flats. A mere 20 minutes' drive from here, the dusty brown earth gives way to a vivid jolt of green: agricultural fields that cover thousands upon thousands of hectares of desert. Flanked by bare, sand-colored mountains, bearded date palms jut from geometric green fields.

The water that fills the pipes and feeds the fields comes from the Colorado River, which has been stretched, splintered, and redirected to bring water 2300 kilometers from the Rocky Mountains, where it begins as melting snowpack. The river ends in Mexico, but a network of canals as long as the river itself sends the Colorado's water coursing through the Imperial Valley's sloping fields, transforming this dry place into an unlikely agricultural powerhouse.

The Colorado, however, is also a vast hydroelectric machine that supplies the Southwest with much of its energy—directly, in the form of hydropower, or indirectly, by cooling massive thermoelectric power plants. "The more energy people need, the more water you need for power plants," says Mike Hightower, an engineer at Sandia National Laboratories who analyzes the competition between water and energy needs.

The intricate relationship between water supply and electricity generation plays out dramatically in the American Southwest. The problem its residents now face is a simple one of supply and demand. The Colorado is governed by agreements collectively known as the Law of the River, which divides up the rights to the water among seven states. The main provisions, set into law in 1922, have never been updated to reflect the region's rapid growth, and they now allocate more rights than there is water in the river. To complicate matters further, several prominent scientists predict

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COLORADO RIVER WATER DRIP-IRRIGATES AL KALIN'S ONION FIELDS AND FLOWS TO GEOTHERMAL PLANTS. BUT LESS OF IT ENDS UP IN THE SALTON SEA, WHERE SALTIER WATER KILLS FISH AND RECEDES FROM DUSTY SHORELINES.

that climate change will cause the river's flow to shrink considerably in the coming years. Tim Barnett and David Pierce, researchers at Scripps Institution of Oceanography, in La Jolla, Calif., say that those competing claims will reach a critical point by 2021. "Water deliveries will have to be cut even beyond the most draconian measures," says Barnett.

How that water will be shared will require some delicate rethinking. "People have a visceral reaction," says Patricia Mulroy, general manager of the Southern Nevada Water Authority. "You can take their gold, you can take their silver, their coal, gas, oil, and move it thousands of miles. Don't *touch* their water."

But the 30 million people who depend on the Colorado River will have no choice but to relinquish some of their supply because, simply put, there just isn't enough water for this growing population and its energy needs. The reasons can be found all along the Colorado's incredible reach, from the cracked deserts gasping for the river's final drops to the enormous reservoirs that showcase its shriveling might [see map, "The Colorado Machine"].

AFTER IRRIGATING THE NATION'S BUTTER lettuce and alfalfa in the Imperial Valley, the dregs of the Colorado River finally dribble into the Salton Sea. This quirky lake collects the last drops of the 3.8 million megaliters of water the valley gets each year.

The valley's water supply is nearly three-quarters of California's total share and enough for the daily needs of the nearby city of San Diego about five times over. Such abundance has never sat well with the residents of that city, which is in constant drought. "They saw water flowing into the Salton Sea," says Al Kalin, an

Imperial Valley carrot and onion farmer. "They could really use it, and they thought we were wasting it."

In 2003, under pressure from the federal government, farmers scrambled to free up some water. The solution appeared simple: New conservation methods would enable the farmers to use less water, setting it aside for San Diego. The farmers did so, largely eliminating the runoff from their fields.

But less water for the valley meant less water to replenish the Salton Sea, which was already choking on fertilizer runoff and heavy metals that leached in from factories in Mexico. Fish died off in spectacular numbers. Kalin says that exotic algae became so abundant that just tossing a rock into the vile stew could ignite a brilliant splash of neon blue as the creatures glowed furiously in self-defense. "My grandchildren love the light show," he says. But Kalin had to stockpile scented candles to combat the stench.

If that was bad, the lack of runoff has been even worse. Without the rivulets from the farms to sustain it, the lake will sink 1.8 meters a year in the desert heat. As it recedes, it exposes a fine silt containing sodium sulfate and selenium. The windstorms that frequently rip through the desert can stir up the selenium, which in humans can bring on neurological problems, cirrhosis, and in rare cases, death. Breathing in sodium sulfate can cause asthma attacks and other respiratory problems.

The Salton Sea's slow death also poses a major problem for the geothermal-energy industry and for the entire state of California. The state has set an ambitious goal of generating 33 percent of its electricity from renewable sources by 2020, and the Imperial Valley would play a big role in making that happen. That's because the major challenge in reaching that target is finding an ample supply of clean, reliable, round-the-clock power, and so far, only geothermal energy fills the bill.

If the lake continues to recede, the impending dust storms will endanger workers at the plants and damage their equipment. "The dust sure wouldn't be good for the turbines," says CalEnergy's Gran. The plants themselves, however, are partially to blame for draining the valley of its limited water supply, and therein lies the conundrum.

The Imperial Valley's geothermal plants use deep wells to tap into superheated rocks thousands of meters below the ground. In one approach, called flashing, the hot, pressurized brine that's trapped in those rocks surges to the surface. There, the pressure change causes some of it to turn to steam, which then drives turbines to generate electricity. Together, CalEnergy's flashing plants produce 342 MW, or enough to power about 250 000 homes.

Flashing plants need relatively little cooling water: Last year, all CalEnergy plants combined used about 4100 ML. However, flashing works only if the plant sits directly over the hottest part of the geothermal field, which in this case is right on the shores of the Salton Sea. And there's much more energy to be had further out in the valley.

To fully harness the region's geothermal potential, prospectors will need a different type of plant, known as binary cycle. Because these can produce energy at lower temperatures, they can be built almost anywhere in the valley. Ormat Technologies operates three such plants. But there's a catch: Its 50-MW binary-cycle facility in Brawley, an Imperial Valley town about 25 km from the Salton

MAP: ANDREW ZBIHLYJ

THE COLORADO MACHINE

The waters of the Colorado River are divided up equally between the upper basin and the lower basin, but shortages are expected. Some of the water goes to energy production—at the Navajo Generating Station coal plant, Hoover Dam, geothermal plants near the Salton Sea, and many other sites.

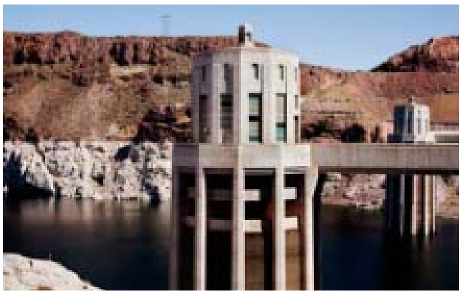
IMPERIAL VALLEY FARMERS HAVE WORKED FEVERISHLY TO CONSERVE WATER FOR DIVERSION TO CITIES. HERE, AL KALIN STANDS ON ONE OF THE LINED CANALS THAT CHANNEL WATER TO HIS FIELDS FROM THE COLORADO RIVER.

Sea, uses over 7400 ML of water per year. That's about 57 Olympic-size swimming pools' worth per week and almost twice as much for one binary plant as CalEnergy uses for all 10 of its flashing plants. To generate steam, the hot brine vaporizes a chemical with a low boiling point, and the resulting vapor drives the turbines. Colorado River water then cools the chemical to condense it back into a liquid, completing the cycle.

No one knows where the water will come from to support the valley's growing geothermal presence. Ninety-seven percent of the water that reaches the Imperial Valley is promised by law to farmers. That leaves a mere 96 000 ML for all the valley's 160 000 residents and their businesses, and of this the geothermal industry has been given a third. "The little we use could be jeopardized if people need the water for farming or municipal uses," says Gran. "In a drought, how do you determine what takes precedence?"

To try to reconcile competing demands, the Imperial Irrigation District, which holds the valley's Colorado River water in trust, recently set tiered fees for the water in the hope that the higher price will let new prospectors extract the valley's geothermal energy without destroying the valley itself. New users who withdraw less than 1233 ML per year pay up to US $493 per megaliter. Those who use more must shell out three times as much. Whatever profit the district makes will go toward water-conservation projects.

Even the geothermal operators aren't convinced that the new pricing scheme will be enough to appease all the users and salvage the warped environment of the Salton Sea. Gran worries that the Imperial Valley lacks the political clout of a big city and that its water will continue to be taken, meaning more trouble for farmers and power producers alike. "The wolves are howling at the gate," he says.



AS A DEPUTY REGIONAL DIRECTOR AT THE BUREAU OF RECLAMATION, TERRANCE FULP [*above*] CATALOGS THE STEADY DROP OF LAKE MEAD.

THE HOOVER DAM'S INTAKE TOWERS [*left*], WHICH WERE ONCE NEARLY SUBMERGED BY THE COLORADO RIVER, NOW JUT NAKEDLY OUT OF THE RECEDING WATER. THE LAKE'S INFAMOUS 38-METER "BATHTUB RING" IS VISIBLE EVIDENCE THAT THE RESERVOIR IS NOW LESS THAN 50 PERCENT FULL.

THE IMPERIAL VALLEY'S PREDICAMENT begins far up the Colorado River at Lake Mead and Lake Powell, the two great reservoirs that make all this water wrangling possible.

The Law of the River allots 9.25 million ML of river water per year to each of two artificially designated basins. The upper basin consists of Colorado,

MORE WATER FOR WATTS

The Energy Information Agency predicts that the United States will add more than 70 gigawatts of thermoelectric capacity by 2030. The National Energy Technology Laboratory figures that this will increase the energy sector's water consumption from 2010's 9500 megaliters per day to between 10 600 and 11 700 ML per day. However, the new generation will be based on cooling technologies that consume (evaporate) more water but withdraw less, so the industry's total daily freshwater needs could fall by as much as 46 500 ML, a savings just shy of the Colorado River's historical average daily flow rate.

Some of the technologies come out of a U.S. Department of Energy program aimed at developing three categories of commercial-ready technologies [at right] for existing plants that could cut their water use by 70 percent for half the cost of existing air-cooling technology.

ADVANCED COOLING
Air cooling radiates a power plant's heat to the air instead of evaporating water. However, it's less efficient than wet cooling, especially in summer heat. Air2Air, developed by SPX Cooling Technologies, of Overland Park, Kan., is an add-on to a traditional cooling tower that condenses 12 to 30 percent of the water that is usually lost to evaporation.

REUSING WATER
Power plants can recirculate cooling water three or four times before it becomes too concentrated with pipe-fouling minerals. Engineers at Philadelphia's Drexel University want to double that by blasting the water with a high-voltage pulse that generates a mineral-shattering shock wave.

NONTRADITIONAL WATER
With the appropriate conditioning, water pushed out of the ground by the injection of carbon dioxide could be used to cool the power plant that produced the carbon dioxide in the first place.

New Mexico, Utah, and Wyoming, and the lower basin is made up of Arizona, California, and Nevada. To ensure that each basin gets its share, the U.S. Department of the Interior's Bureau of Reclamation uses Lake Mead and Lake Powell as water banks. The trouble is, there probably isn't 9.25 million for the lower basin, says Terrance Fulp, deputy regional director of the bureau's Lower Colorado region. For now, the numbers work only because some states, such as Utah and Wyoming, don't claim all their water. But the populations in those states are growing, and each will soon want to claim its full rights, says Scripps's Barnett.

Without some new and extraordinary measures, that demand will be impossible to meet. The Hoover Dam, finished in 1936, halted the rushing river and created a placid water vault—Lake Mead. The lake is 372 meters deep when full, but that level hasn't been seen in 10 years. A drought that began in 1999 has caused the reservoir to drop more than 3 meters a year.

Today Lake Mead looks naked. The retreating water line has exposed a broad white stripe of calcite, a glaring "bathtub ring" that lends an air of vulnerability to the shrinking lake. "We used to go cliff diving all the time in Lake Mead," says a nurse in Henderson, Nev. "Now we wouldn't dare."

At press time, the elevation of Lake Mead hovered perilously around 335 meters. If the lake drops 8 more meters, the Bureau of Reclamation will sharply curtail water deliveries in a desperate bid to prevent the water level from sinking further.

When the reservoir is at normal elevations, Hoover Dam's 17 turbines have a combined generating capacity of 2080 MW. By February, the lake's decline had cut the dam's capacity by a fifth. But lower output is only the first symptom of an ailing hydroelectric system. When the lake level sinks and the pressure gets too low, air bubbles form on the turbine blades, and the generators start to shudder violently. "The magic number is 320 meters," says Hoover facilities manager Peter DiDonato. "That's when the turbines start to shake. You can feel it. The whole building will shake."

The vibration can damage the turbines to the extent that the engineers may stop production altogether. Shutting down the generators would be a huge blow to the three states that depend on the dam's power, and it's not an option that DiDonato likes to consider. "We just don't know, because we've never been there," he says.

The dam's stakeholders are now investing millions of dollars in new turbines that can function even at lake elevations that jeopardize the existing ones. Engineers plan to install the first such turbine in 2012. But new turbines alone won't solve the underlying problem. Lake Mead simply has less water than it did before, and that's a big concern for everybody who relies on the river.

FARTHER UPSTREAM, THE ENERGY problems are no less complicated. Before it reaches Lake Mead, the Colorado winds southwest across the top of Arizona from the river's other major reservoir, Lake Powell, situated on the border of Utah and Arizona. This lake was formed by damming the river at Glen Canyon and drowning the picturesque valley. The backed-up river filled in dozens of small gorges along its length, so from space the lake looks like a squashed centipede. But up close, it's beautiful—a sprawl of red-tinged buttes with verdant alcoves hidden among the cliffs.

On the Arizona side of the lake, near the town of Page, there is more evidence of what drought on the Colorado is doing to

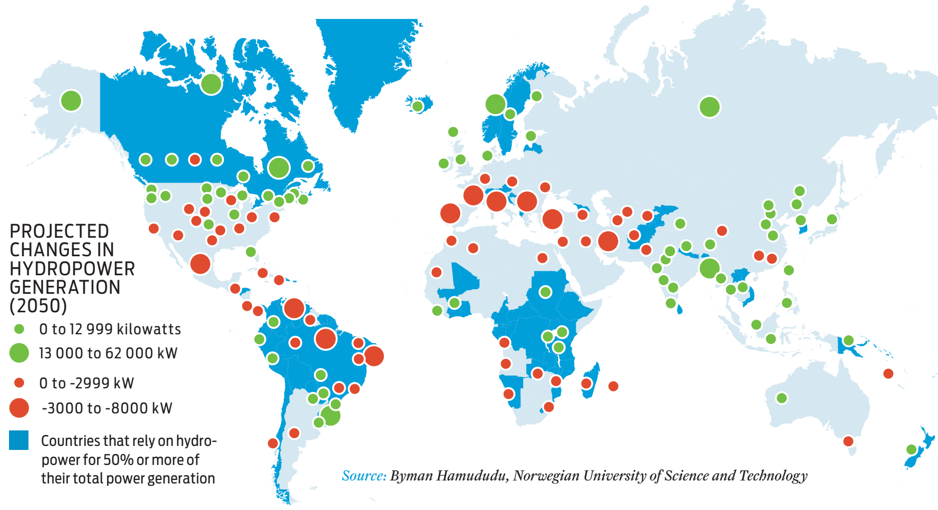
THE FUTURE OF HYDROPOWER, AT A GLANCE

The energy in river water supplies about 20 percent of the world's electricity. In 2005, that amounted to 2900 terawatt-hours. More than 60 countries get over half their electricity from hydropower. And dam building continues apace, most notably in Brazil, China, and India. But climate fluctuations make predicting future hydropower output tricky. In some places, shrinking rivers have reduced or even shut down power generation when dam reservoirs dropped below critical levels. As a result, drought-stricken countries like Kenya, the Philippines, and Venezuela have suffered periodic blackouts and electricity rationing in recent years.

Using results from 12 climate models, researchers at the Norwegian University of Science and Technology examined how the world's rivers will likely change over the next 40 years and what that will mean for hydropower production. They found that while midlatitude areas will generally experience reductions in river flow and thus hydropower output, some areas, such as northern Europe, eastern Africa, and Southeast Asia, will probably see a boost.

As expected, the most at-risk areas are those where a high dependence on hydropower will run headlong into decreasing river runoff. In southern Africa, for instance, drier conditions could mean a decline of 70 gigawatt-hours in hydropower capacity. Venezuela, parts of Brazil, Afghanistan, and Tajikistan are also likely to be hit hard. —*Anne-Marie Corley*

For more, see http://spectrum.ieee.org/hydropower.



Source: Byman Hamududu, Norwegian University of Science and Technology energy production. A pumping station pulls water from a brand new tunnel below the lake's surface to cool the Navajo Generating Station. The 2.25-gigawatt coal-fired plant located on the Navajo Nation reservation powers cities from Tucson to Los Angeles. It was built to provide electricity for the Central Arizona Project (CAP), a sprawling water distribution scheme that uses hundreds of pumps, canals, and dams to stretch the Colorado's water over much of Arizona. The CAP water travels 540 km from the California border, mostly uphill, with some of it being diverted along the way to Phoenix and Tucson, two of the country's fastest growing cities. Navajo guzzles Colorado River water to cool the steam for its turbines, condensing the water for reuse in the plant's boilers. It's the pressure difference between the cooled condensate and the hot steam that drives the turbine.

Since the start of the Colorado's decadelong drought, Navajo's operators have worried about the security of their water supply. "We started to see Colorado River runoff drop to levels that no one had seen before," says Jim Pratt, the manager of generation engineering for Salt River Project, a southwestern water and power utility that owns a major stake in Navajo. Pratt and others calculated that if the drought continued, the power plant's inlet at Lake Powell would be sucking air by 2005, halting production. Thanks to a few closer-to-normal years of snow and rain, disaster didn't arrive so quickly. Lucky thing, too, because it took until last December to bore through the local sandstone and install a new inlet on the lake, 45 meters below the original.

The new water tunnel has bought the plant a margin of safety. But if Lake Powell shrinks even more, the plant's future will again be in peril.

THE REDUCED HYDROPOWER FROM DAMS like Hoover and the possible loss of plants like Navajo mean electricity shortages in the West. Engineers at Argonne National Laboratory simulated the effects of drought on the Western grid and found that losing that water would increase electricity costs some $4 billion and leave a shortfall of 161 gigawatt-hours, enough to black out Los Angeles for two days. Electricity bills would rise as much as 34 percent in the summer, and because of the links between electricity and water—such as Navajo's role in slaking Tucson's thirst—higher water bills would likely follow.

The Argonne simulations used past droughts as a model, but if some climate models are to be believed, future shortfalls on the Colorado will be much worse. In a 2008 report, Scripps researchers Barnett and Pierce predicted that without intervention, Lake Mead has a 50 percent chance of running dry by 2021. Because the Bureau of Reclamation's Fulp will do everything in his power to prevent that, Pierce says, the real issue is what measures he will have to resort to.

Barnett and Pierce's analysis hinged on two main factors. First, human-

THE CARBON-CAPTURE CONUNDRUM

Coal power's carbon savior could double its water woes

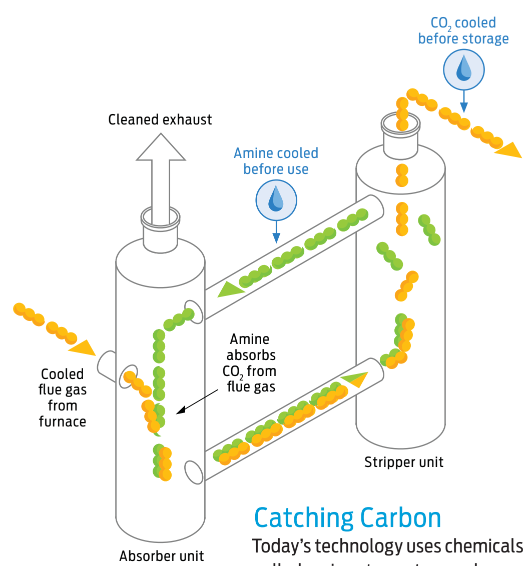
Despite all the talk of moving to greener energy sources, coal will be with us for the foreseeable future. It's just too cheap and plentiful. But if we're really serious about cutting carbon dioxide emissions, coal plants everywhere will need to substantially reduce the billions of metric tons of CO_2 they annually emit into the atmosphere. The big hope is that in the next few years the plants will begin capturing and storing a large portion of that CO_2 deep underground, in the oceans, or in mineral form.

But the technology needed to capture carbon has a huge downside: It could nearly double the amount of water a plant uses for every kilowatt of electricity it delivers—easily erasing any gains from techniques aimed at conserving water.

"This technology was not developed in a water-constrained environment," says Jared Ciferno, technology manager for the existing plants program of the National Energy Technology Laboratory (NETL). "The bottom line is that [carbon] capture takes energy, and that translates to additional water use."

Just how much water is pretty shocking. By 2030, the addition of carbon-capture technology would boost water consumption in the U.S. electricity sector by 80 percent, or about 7500 megaliters per day, according to research at NETL, which is operated by the U.S. Department of Energy. For plants in water-stressed areas, that's a deal breaker. "It is not likely that there is enough water supply available to any of our plants to allow for double the water use," says John Coggins, manager of resource planning at Salt River Project, a water and energy utility in Arizona.

The 80 percent figure assumes that the electricity generation lost to powering the carbon-capture system is made up for by adding more water-cooled coal-fired power. In other words, for a 550-megawatt plant to both capture its carbon and still deliver 550 MW of electricity, it would need to add more than 125 MW of additional generating capability to cover the energy used in capture. If you don't make up for the lost generation, or make it up in some way that requires no water and emits no carbon—with a wind farm, say—the additional water consumption is more like 40 to 50 percent, according to NETL's Ciferno.



Catching Carbon
Today's technology uses chemicals called amines to capture carbon dioxide. Water is used to cool the amines and help compress the captured CO_2.

ILLUSTRATION: EMILY COOPER

induced climate change has reduced the amount of snow that feeds the river. That alone may be enough to bankrupt the system within two decades, Barnett says. The second factor has stirred up more controversy. According to several tree-ring studies from the University of Arizona, the river's flow during the 20th century was higher than it had been during the previous 150 years. So the people who divided up the Colorado River's water did so during the wettest part of a very wet cycle and mistakenly assumed that naturally occurring water supplies would remain the same. "They're planning on an average water flow in the Colorado that exists maybe once in a thousand years," says Barnett. "They're assuming money in the bank that they do not have."

Not everyone agrees with the Scripps scientists' predictions—notably Fulp. But some water managers are listening. "People argue with [Barnett and Pierce's] assumptions and probabilities," says Mulroy, who manages the water supply for Las Vegas, which depends on Lake Mead for over 90 percent of its water. "And I say, who cares what the probabilities are? Can you say it's impossible? And if it's not impossible, you'd better have a contingency plan." ❑

That's still a lot of water. For coal power plants, the state-of-the-art carbon-capture technology is known as amine-based wet scrubbing [see "Catching Carbon"]. It's basically the technology that puts the fizz in your Fanta. First, the plant's flue gas is scrubbed of sulfurous nasties; what's left is a mixture of nitrogen, water vapor, and CO_2. An amine solution then reacts with the CO_2, yielding a gas stream of mostly nitrogen, which goes out the smokestack, and a CO_2-rich amine solution. The solution is heated to strip the CO_2 from the amines. The CO_2 is then cooled and compressed for storage, and the amines cycle back to pick up more CO_2.

Why does this process demand so much water? It's all about the cooling. The power plant's cooling tower carries heat away by evaporating water. Cooling the amines for CO_2 absorption—which generates heat in itself—leads to an additional load on the cooling tower, causing more water to be lost. And compressing the CO_2 to the supercritical conditions needed for storage requires cooling, too. (A less-water-intensive process would be used for integrated gasification combined cycle and oxyfuel plants, but the former technology is used in only a slim minority of generators, and the latter is not yet in operation [see "Restoring Coal's Sheen," *IEEE Spectrum*, January 2008].)

To really reduce CO_2 emissions, says Ciferno, less thirsty forms of carbon capture will have to be developed. His lab is now focused on reducing the amount of energy involved, betting that this will take care of carbon capture's water woes, too. With a budget of about US $50 million per year and 40 projects, NETL has perhaps the biggest R&D program in this area. The goal is commercial-scale technology by 2020 that can capture 90 percent of a coal plant's CO_2 while increasing the cost of generating electricity at that plant by less than 35 percent.

Industrial firms already have several pilot projects capturing small streams of CO_2 at plants in Europe and the United States. However, none have yet been scaled up to the size that would make a noticeable difference in a plant's water consumption. France's Alstom Power, for one, uses chilled ammonia instead of amines, which the technology company says should be more energy and water efficient. Alstom tested the process last year with a 20-MW pilot plant at American Electric Power's New Haven, W.Va., generating station. AEP now plans to use it to capture carbon from 235 MW of the New Haven plant's 1300-MW capacity, starting in 2015.

Germany's Siemens Energy has also developed an alternative technology, which relies on amino-acid salts instead of amines. Amino-acid salts pick up more carbon than amines do, so you need to pump and cool less material, says Tony DoVale, president of Siemens Environmental Systems and Services. So far the process has been demonstrated to capture carbon while leaching only 9 percent of a plant's power, compared to amine technology's typical 20 percent. That "would ultimately imply half the cooling load," says DoVale.

Of course, unless plant operators are compelled to capture carbon, these energy and water costs won't be borne at all. "Why would you put on a piece of equipment that puts 10 percent of a plant's output away if you didn't have to?" says DoVale.

—*Samuel K. Moore*

The Water Cost of Carbon Capture

Adding carbon capture to a coal plant substantially increases its water use per watt. Because carbon capture takes a substantial amount of energy, if a plant is to continue to deliver the same amount of electricity and capture carbon at the same time, it must add generation capacity. So a 550-megawatt plant with carbon capture might need to actually produce 675 MW of power.

TECHNOLOGY	WITHDRAWAL[1] (L/MWh)[3]	CONSUMPTION[2] (L/MWh)
Steam turbine	2300	1900
WITH CARBON CAPTURE	4500	3400
Supercritical water turbine	2100	1500
WITH CARBON CAPTURE	4000	3000
IGCC[4]	1500	1100
WITH CARBON CAPTURE	2300	1900

1. Withdrawal: Water that is removed from the ground or diverted from a surface-water source for use, some or all of which may be returned to that source 2. Consumption: The amount of water a plant uses that evaporates away or cannot otherwise be returned to its source. 3. Liters per megawatt-hour (rounded to the nearest 100 liters) 4. Integrated gasification combined cycle

Source: "Estimating Freshwater Needs to Meet Future Thermoelectric Generation Requirements—2009 Update," U.S. Department of Energy, National Energy Technology Laboratory

THE TROUBLE WITH NATURAL GAS

Thanks to a combination of extraction technologies, there's a lot more natural gas within reach now than anybody had thought possible. The new techniques, colloquially called fracking, led estimates of U.S. gas reserves to jump a whopping 45 percent last year, giving the country enough fuel to meet its gas needs for about 90 years. Newly accessible shale gas reserves may be equally enticing in other parts of the world, notably China and Eastern Europe.

But no matter where these new technologies are used, there's a catch, and it's not a small catch. It's water.

To begin with, the recovery of shale gas requires large quantities of water, which is injected to break up deep rock formations. The quantity of water involved may not be a big issue in water-rich places, but the effect of shale gas extraction on water quality is.

The water that's injected contains a complicated recipe of chemicals, and by the time it's been recovered after injection it has picked up still more chemicals, including a lot of salt and sometimes radioactive materials. Those chemicals, and the gas itself, can contaminate local water sources. Considering that some of these supply water to places like New York City, much of the gas may be recoverable in theory but not in practice.

Find out more at http://spectrum.ieee.org/natural-gas.

THE LONG HAUL

China's massive water-diversion project aims to tackle severe water shortages, but it has big problems of its own

BY ANNE-MARIE CORLEY WITH YU-TZU CHIU
ILLUSTRATION BY ANDREW ZBIHLYJ

In 1952, Mao Zedong visited the great rushing rivers of China's south and suggested that the thirsty north "borrow" some. Thus was born the South-to-North Water Diversion Project.

Nearly 60 years later, construction is under way on the biggest water redirection scheme in history. When complete, the US $62 billion project will transport 44.8 million megaliters of water per year from the lush river valleys of the south to the parched industrial north—enough to flood Beijing to a height of almost 3 meters. The three-pronged project, which consists of an eastern route, a western route, and a central route, includes the construction of more than 1800 kilometers of pipelines and reinforced canals, at least 23 pumping stations, up to 7 dams, and 2 massive tunnels under the Yellow River. Some parts won't be finished until midcentury.

The northern need for water is great. According to a 2005 report from the China Institute of Water Resources and Hydropower Research, northern China is home to about 44 percent of the population but has only 14 percent of the water. In the northern industrial city of Tianjin, the destination of the project's eastern route, the amount of freshwater available per capita is well below 1 ML annually, the level most water experts consider essential to meet basic needs.

What's more, Chinese industry is concentrated in the north, as is the energy production that drives it. China's thermoelectric power plants will need 82 million ML of water per year by 2030.

Such a big project will have big consequences. Draining one river to fill another, as the western route does, will upset the balance of power—literally—in the string of hydroelectric dams along the Yangtze River. And some destinations, such as Tianjin, don't even want the water, because of its high cost and poor quality.

Officials can't even claim that the project will meet the north's needs. "In the short term, it might ease the water shortage in the north," says Ma Jun, director of the Beijing-based Institute of Public and Environmental Affairs. But in the long term, Jun says, conservation and efficiency measures must help solve China's water crisis.

WESTERN ROUTE

LESS POWER, MORE PROBLEMS

To refill the dwindling Yellow River from the headwaters of the Yangtze, the western route will require tunneling through mountains, crossing earthquake fault zones, and traversing the 3- to 5-kilometer-high Qinghai-Tibet Plateau. The project will also need new pumping stations and massive dams.

The plans, still in the works, are drawing fire from engineers and environmentalists both inside and outside the Chinese government. One of the many concerns is that siphoning water from the Yangtze will likely cause hydropower shortages—around 70 stations supply 770 million megawatt-hours of electricity annually along the Yangtze. One estimate puts the annual energy loss after water diversion at 111 million MWh per year.

LENGTH
Unknown; government feasibility study continues

THROUGHPUT
17 million ML/year

CONSTRUCTION PERIOD
2010 to 2050

ENERGY CONSUMED
Unknown

LATEST NEWS
The western route is slated to break ground this year, but no firm date has been set.

CENTRAL ROUTE

SHRINKING SOURCE

The source of the central route, the Danjiangkou Reservoir, has reportedly shrunk due to decreased flow from the Han River. To enable it to send more water north, Danjiangkou is being expanded to a storage capacity of 29 million megaliters. This would mean raising the water level from 157 to 170 meters and relocating 330 000 people who live or work in the floodplain. But increasing the reservoir's size won't make more water flow into it from the Han.

LENGTH
1415 kilometers

THROUGHPUT
12–14 million ML/year

CONSTRUCTION PERIOD Began 2003; missed targeted 2008 and 2010 completion; rescheduled for 2014

ENERGY CONSUMED
0 megawatt-hours (gravity powered)

LATEST NEWS
As of February, 4500 residents had been relocated to make way for reservoir expansion. The relocation is set to be completed by 2012.

EASTERN ROUTE

DIRTY WATER AND DESALINATION

Tianjin has reportedly refused to accept water from the eastern route, claiming that it will be too polluted. The city has instead invested in seawater desalination, which now supplies it with 200 megaliters of freshwater per day; this amount should rise to 500 ML within five years. Desalination could be cheaper than eastern route water; according to officials, it costs about 5000 yuan (US $732) per megaliter to desalinate water in Tianjin, while estimates for the piped water are about 18 000 yuan per megaliter.

LENGTH
1156 kilometers

THROUGHPUT
14.8 million ML/year

CONSTRUCTION PERIOD
Began 2002; missed targeted 2007 completion; rescheduled for 2013

ENERGY CONSUMED
8.9 million MWh/year from 30 pumping stations between the Yangtze River and the Yellow River; 0 MWh/year from the Yellow River to Tianjin (gravity powered).

LATEST NEWS
In March, the first 585-meter-long tunnel for crossing under the Yellow River was completed.

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UNEASY HARVEST

AUSTRALIA ▪ INDIA

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SPECIAL REPORT ▪ WATER VS. ENERGY

LIFE IN DROUGHT

In Australia, the driest inhabited continent, saving water increasingly means spending watts

BY JEAN KUMAGAI
PHOTOS BY BRAD DeCECCO

"I LOVE THIS PLACE, AND I LOVE FARMING. BUT I LIKE WHAT WE USED TO DO, NOT WHAT WE'RE DOING NOW."
—GERARDINE HILL, SHOWN WITH HER HUSBAND, TREVOR, ON THEIR RICE FARM IN GRIFFITH, NEW SOUTH WALES, AUSTRALIA

TREVOR HILL STANDS KNEE-DEEP in water at the edge of his rice field. He reaches down with a weathered hand, plucks a green stalk, and carefully cuts a slit along the stem. He coaxes out the delicate strand of pale green rice kernels and then holds it up to the sunlight. It's still more than two months to harvest time, but to his eye the crop looks good.

The rice fields on Hill's farm in New South Wales, Australia, form an emerald expanse that stretches to the horizon—until you turn around. Across the dirt road, the land is brown and bare. In wetter times, he'd plant rice on nearly a third of his 412 hectares; this year he has enough water to irrigate just 44. Like many local farmers, he's hired contractors to smooth out even the slightest variations in his fields' topography, and he uses satellite imagery to diagnose the health of the soil, measures designed both to reduce water consumption and boost production.

After the harvest, he'll sell the rice stubble to cattle farmers. On the water that remains in the ground he'll sow a crop of oats or barley. Throughout the summer, his lambs will munch on weeds and grass along the banks of the rice paddocks; eventually he'll auction them off for about AU $130 a head. And after all that, Hill will be lucky to break even this year.

His wife, Gerardine, grew up on this farm, reachable by gravel road about 15 kilometers from Griffith, the agricultural heart of central New South Wales. The couple has raised three children here. Their yellow-brick ranch house is cheerful and inviting, and a rose garden adorns the foot of the sloping yard. There are animals everywhere—chickens, ducks, two sheepdogs, and a chatty long-billed Australian cockatoo named Charlie. But the Hills are seriously thinking about moving on.

"I love this place, and I love farming," Gerardine says. "But I like what we used to do, not what we're doing now." These days, the state government sends a mental-health worker to monthly meetings in town, a routine prompted by an uptick in suicides in the past few years.

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A WORKER FROM MURRUMBIDGEE IRRIGATION INSTALLS NEW PUMPS AND PRESSURIZED PIPELINES THAT WILL REPLACE OLD GRAVITY-FED CHANNELS *[middle right]*. THE MOVE WILL SAVE WATER BUT USE MORE ELECTRICITY.

Being a farmer has never been easy. And Australia has never been the easiest place to do it. It's a largely dusty continent where droughts can span decades, only to give way in a day to torrential storms that can go on until the dams overflow. Even so, there's no precedent for what's been happening here. The last eight or nine years have been the driest since European settlement began two centuries ago. And it's unlikely to get better anytime soon. Computer models predict that in coming decades much of Australia will become hotter, windier, and drier.

Even ordinary Aussies are starting to sound a little panicked. A talk-radio caller lobbies for relocating the country's agricultural center to Tasmania. A taxi driver in Sydney wonders why the government isn't building a giant pipeline to pump water from the country's tropical north to the arid south. A retired academic suggests floating huge freshwater-filled balloons along the eastern seaboard to replenish depleted waterways.

The Australian government has responded to its water woes with a raft of big projects. Its 10-year, $12.9 billion (US $11.8 billion) "Water for the Future" plan, whose aim is to "prepare Australia for a future with less water," includes $5.8 billion to modernize irrigation infrastructure. [Note: All figures in this article are in Australian dollars.] The program should save millions of megaliters of water but will burn many more megawatts, too. That's because water-saving techniques like drip irrigation and pressurized pipelines carry a stiff energy penalty.

New projects also tackle water usage in cities, where close to 90 percent of the population now lives. Of these efforts, the most ambitious is South East Queensland's $9 billion water grid, which promises to drought-proof the region. In doing so, it's also boosting the electricity consumed by the water system. That's because of the new reliance on energy-intensive water technologies like desalination and wastewater recycling.

Even as this country of 22 million people contemplates its dry future, it is already facing a startling reality: From here on, there will be no easy solutions. The future will bring only complex and sometimes heartrending trade-offs.

"FOREVER UNINHABITABLE AND USELESS for all the purposes of civilized man." And so Australian surveyor John Oxley dismissed the desiccated plains of central New South Wales nearly 200 years ago.

Now that same area abounds with citrus groves, vineyards, cherry orchards, and rice fields. What sustains all that lush verdure is an irrigation network that can move up to 8.5 billion liters of water every day from the mighty Murrumbidgee River to the sparkling irrigation channels that crisscross 120 000 hectares of farmland.

Those earthen and concrete channels, some nearly a century old, lose about 5 percent of their water through evaporation and leakage. Once the water reaches a farm, losses can be even higher if inefficient irrigation methods are used. So with funding from the government, Murrumbidgee Irrigation (MI), which is based in Griffith and operates the network, is replacing about a third of the channels. Instead of the old, gravity-fed network, high-pressure pipelines and pumping stations will now keep the water moving and under pressure. Those pipes and pumps, as well as the pipes and pumps on individual farms, all require electricity. The move will save water but will also consume $2.5 million worth

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of electricity a year, says MI managing director Brett Tucker.

"For nearly a hundred years, we've been a deliverer of water," Tucker says. "We recognize now that we also deliver energy, because it's embedded in the water, one way or other." The electricity costs will be passed along to water customers. "Energy isn't getting any cheaper," he says. "Our customers are worried."

But pricey electricity isn't the farmers' only worry. Water now carries a price, too. Each year, Australian farmers who rely on irrigation receive an allocation of available water, for which they pay a management fee; any extra water must be bought by the megaliter in a national market in which prices can fluctuate wildly. When it rains—no surprise here—water is cheap. But in a dry summer the price can soar, as it did three years ago, when a megaliter was trading at $1200.

For a farmer like Trevor Hill, who needs about 15 megaliters (ML) per year for each hectare of rice, unpredictable prices are a serious challenge. This past season, water started at about $300/ML, falling to a more reasonable $130/ML in late January. By then, though, with the season two-thirds over, the lower price meant almost nothing to Hill's bottom line.

INTERCEPTION SCHEMES LIKE THIS ONE IN NEW SOUTH WALES KEEP SALT OUT OF THE MURRAY-DARLING BASIN'S WATERWAYS. BUT DROUGHT AND OVERALLOCATION OF WATER HAVE LEFT THE BASIN "UNBELIEVABLY STRESSED."

One of the goals of the market is to compel farmers to save water. Agriculture accounts for about 65 percent of Australia's water use, so it's the most logical place to look for efficiencies. In general, farmers have responded. About half of the fruit and other horticultural farms in the MI district have adopted drip irrigation or microsprinklers, which precisely release water, fertilizer, and pesticides right at a plant's roots.

But the market's rules can also lead to odd outcomes. In Griffith, everyone knows someone who's decided to trade his water and sit out a season, turning a tidy profit by growing nothing. A few farmers have even sold their water rights permanently; you can do that in Australia, because water and land are now bought and sold separately.

Let's say you own a wheat farm. You could sell your house, barn, and land to one person, perhaps a retiree who aspires to a rural lifestyle. Then you could sell your water rights to someone else, such as a farmer hundreds of kilometers away.

That last part of the scenario bothers Mike Neville, the mayor of Griffith. The last thing he wants is a waterless town. And so he's come to view water as a community asset, like a good public library (which Griffith has) and nice green parks (ditto).

"We've got to make sure this area remains attractive so that people want to bring water into the district, as opposed to trading it out," Neville says. "What good is it if there's no water?"

JUST HOW MUCH WATER GRIFFITH HAS or doesn't have at any given time isn't always clear. A water license entitles the bearer to a certain allocation of water, typically measured in hundreds or thousands of megaliters. But the licenses were established in the much wetter days of the mid-1980s. Today the drought means that a Griffith farmer is often legally entitled to water that doesn't exist. The same paradox exists for water users along the Colorado River in the United States [see "The Power of Water" in this issue].

The Hills carefully track their water account on their home computer. Their license is for 1570 ML of water per year, but nearly all of that is designated as a "general security" allocation, meaning that during dry seasons, they may get only a small fraction of it or none at all; if they need more water, they have to buy it on the open market. Last October, MI informed them they would receive only 7 percent of their general-security water, so they decided to buy an additional 210 ML. That still wasn't enough water for the 44 hectares of rice that Trevor intended to plant, but he took a gamble that either the allocation would grow or that the market price would stay low. His bet paid off: Rainfalls upped the allocation to 30 percent, which left the Hills with just enough water to finish the sea-

A DRY LAKE BED AWAITS WETTER TIMES.

ALGAE CHOKES A CREEK NEAR EUSTON, NEW SOUTH WALES.

CLOCKWISE FROM TOP RIGHT: IRENE DOWDY/MURRAY-DARLING BASIN AUTHORITY; ARTHUR MOSTEAD/MURRAY-DARLING BASIN AUTHORITY (2)

son. Three years ago, though, they made a similar play and wound up losing their entire rice crop.

"We're always on the computer, worrying about water and trading," says Gerardine. "You try to plan, but you can't really plan, because the availability of water is so unknown."

FARMING MAY SOON GET EVEN TOUGHER, at least for those who make their living in the Murray-Darling Basin, which has long been Australia's food bowl. Named for the two main rivers that flow through it, the basin covers a little over a million square kilometers in southeastern Australia, encompassing portions of five states, including the rice farms of Griffith, New South Wales.

More than 150 years of farming and grazing have left the region in rough shape. For years, the biggest problem in the basin was salt. Australian soil naturally contains a lot of it, deposited by ancient inland seas and salt-laden winds off the ocean. Ordinarily the salt would have stayed where it was, but irrigation raised the water table in many areas and, along with it, the salt from deep below ground. At one point, an estimated 1200 metric tons of salt were being flushed into the Murray and Darling Rivers every day, and overirrigation had rendered nearly a million hectares of farmland either too waterlogged or too saline, or both.

Starting in the late 1980s, the government began limiting how much salt each of the basin's five states could release into the rivers. At a number of sites, elaborately engineered schemes were constructed to intercept the highly saline groundwater before it reached the rivers and instead pump it into reservoirs or deep aquifers. This has prevented some 370 metric tons of salt per day from entering the rivers. (Unexpected epicurean bonus: Murray River Salt, pink and flaky, is now sold as a gourmet condiment.)

"We dealt with the salinity problem remarkably well," says Mike Taylor, chairman of the Murray-Darling Basin Authority, a federal agency charged with overseeing the region's ecological revival. "What we weren't dealing with were the environmental impacts from the overallocation of water. And now we find the system unbelievably stressed."

"Stressed" can mean lots of things: pesticide and fertilizer runoff that triggers rampant algal blooms; healthy streams reduced to muddy puddles; infestations of carp that push out native fish; the dying off of native trees and grasses; the disappearance of entire wetlands, and with them, all the birds, fish, and animals.

Taylor's organization is now drafting a plan, due out later this year, that aims to fundamentally change the way Australia manages water in the basin. This time, engineering fixes alone won't do the trick. This time, people will simply have to use less water. Government scientists working with Taylor's group are now figuring out how much groundwater and surface water is actually available. Next, they'll set limits on how much of it can be used.

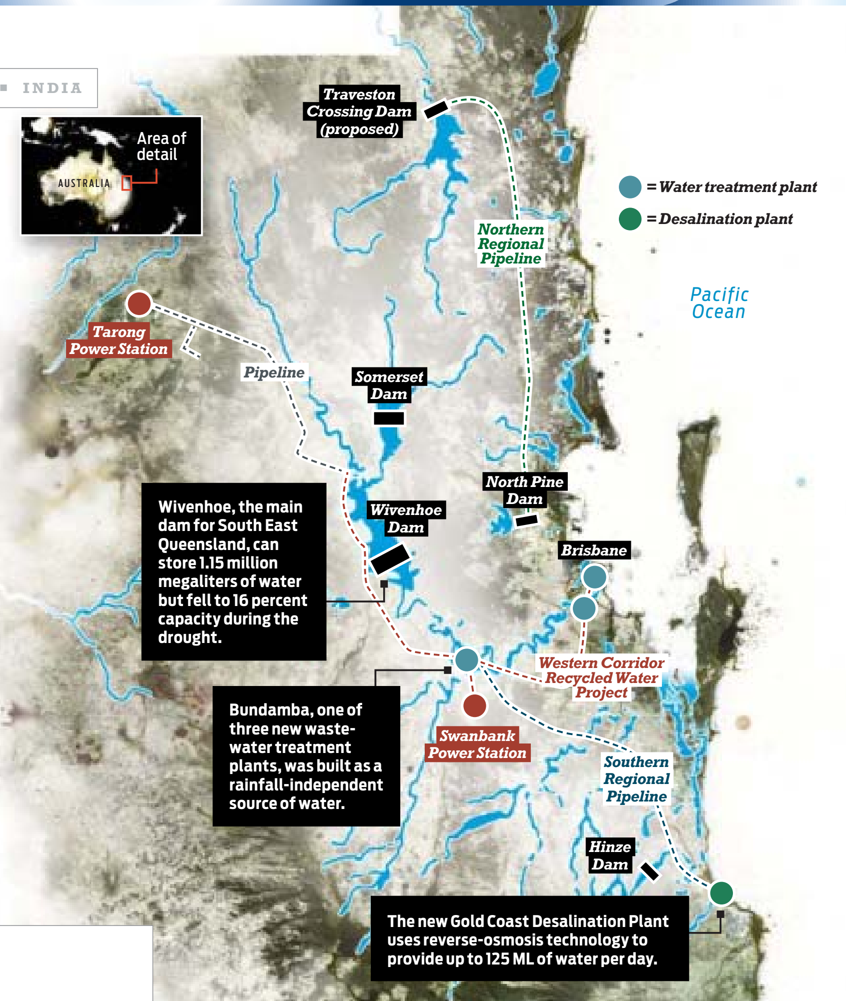
The goal is to ensure that enough water is set aside to keep the basin's rivers, streams, and wetlands healthy. Only after the environment's needs have been satisfied will the government consider other users—irrigators, towns, industry, electricity generators. The amount of water available to them "almost certainly will contract," says Taylor. That process has already begun: Several years ago, the government began buying up water rights throughout the basin, primarily from irrigators. By the end of 2009, it had purchased 766 billion liters of water entitlements worth just over $1.2 billion.

Farmers are fretting about their water being diverted to swamps and billabongs. Alister Watt has lived and worked in Griffith since 1974, first as a livestock broker and now as a water broker. Although he earns his living from the same water market that eventually will allow the government to reduce the water allocation to farmers, he's skeptical about the plan. "Everybody is making radical decisions on the management of water in times when it's very, very dry," Watt says. "One day, the old fella upstairs is going to make it rain, and everybody will get wet. What are they going to do with the water then?"

Australian rivers, he notes, aren't like other rivers. It's normal for the Murray and the Darling to dry up altogether during very dry years. Why exert so much effort to preserve a state of nature that may not, in fact, be natural?

Chris Davis, a water expert at the University of Technology Sydney and a member of Australia's National Water Commission, concedes that "everybody's perception of what's natural is different." Still, he says, it's pretty clear that parts of the basin need urgent attention. "The plan will make or break the basin," he says.

Taylor's group has its work cut out for it, Davis adds. "The irrigators will be unhappy, the environmentalists will be unhappy," he says. "If anybody is totally happy, then [the Murray-Darling Basin Authority] has got it wrong."



WHEN IN DROUGHT...

Modeled on an electricity grid, the South East Queensland water grid has 340 kilometers of pipeline connecting 14 storage dams and weirs, a desalination plant, and three water treatment plants. Though it will allow the region to withstand future droughts, the grid uses lots of electricity to treat and move up to 182 million liters of drinking water each day.

IT'S POURING IN BRISBANE, QUEENSLAND, on a Sunday morning in February. Not a half-hearted sprinkle, not a spitting mist, but a hefty, healthy soaking, the kind that sends pedestrians dashing for cover in the nearest doorway.

By mid-March, a series of such deluges had almost completely topped the storage dams that supply water to this city, the capital of Queensland. Less than three years earlier, though, a prolonged drought had left those same dams at just 17 percent capacity and the entire region scrambling for options.

Now, there are a few things you can do in a drought: You can conserve water, you can channel it from where it is to where it isn't, or you can find new sources of it. Brisbane did all those things and more. The region's massive response revealed the importance of planning on a timescale greater than just a decade or two. But it also brought to light the inevitable trade-off between water and energy: South East Queensland engineered a drought-proof future for itself, but one in which energy consumption for water has soared.

The drought's first surprise was the enthusiasm with which Brisbane residents embraced water conservation. The government urged them to reduce their personal water consumption to no more than 140 liters per day—about what it takes to fill a bathtub. People could water their gardens or wash their cars only with buckets and only during designated times. The government also pushed low-flush toilets, low-flow showerheads, and water-efficient dishwashers and washing machines. The local newspaper gave away vouchers for 4-minute shower timers.

Su-fern Tan, an architectural engineer who lived in Brisbane then, recalls that time with a certain fondness. "When we were stuck in traffic, those signs that normally say 'Slow down, heavy traffic' instead said 'Come on, Brisbane, let's get down to 140 liters per person per day,' " Tan says.

Much to everyone's surprise, residents cut their daily water use from a predrought 300 L to 129 L. "It was so brilliant," Tan says.

Around the same time, the Queensland government began building a $9 billion water grid extending across the state's southeast end, a 23 000-square-kilometer area. The grid hooked up 14 existing dams and weirs as well as a new desalination plant and three advanced wastewater-treatment plants.

More than 4000 people worked on the construction of the water grid, but none with more zeal than Barry Dennien. "Barry's like the evangelist of water," says Chris Snape, a program manager in the South East Queensland Water Grid Manager's office, which oversees the grid's operation. "I've never seen anyone as passionate about water."

When the drought started in 2002, Dennien was working for the Queensland Water Commission, where he was executive director for regional planning and policy. The job title was largely aspirational; water wasn't handled as a regional issue. Each municipality set its own water restrictions, and there were 16 bulk water suppliers, each with its own territory.

"You could drive down a street and on one side people weren't allowed to water their garden or wash their car," Dennien recalls. "And on the other side, they had unlimited use of water. So they'd shoot water across the street to their neighbors! How crazy was that?"

As dam levels continued to drop, planners in the Queensland government, including Dennien, saw a way out of the crisis. Much like an electricity grid, a regionwide water grid could link up the storage dams and move the water to where it was needed. Rather than relying solely on rainfall flowing into the dams, they pushed for rain-independent sources: desalination and water treatment technologies advanced enough to turn sewage into drinking water.

In 2006, the water grid plan was adopted, and in just under two years, the desalination plant and advanced water treatment plants came online, with a total planned output of close to 300 million liters of water per day—about half the region's needs. Hundreds of kilometers of pipelines were constructed, capable of moving up to 182 million liters of drinking water per day. And water management was streamlined and made truly regional: The 16 bulk water suppliers were merged into seven, each with its own specialized function, with the SEQ Water Grid Manager's office at the top and Barry Dennien as its CEO.

IN EARLY 2008, JUST AS THE PIECES OF the grid were coming together, a funny thing happened: It started to rain. Last November the drought was officially declared over.

At the height of the drought, opinion polls had shown more than 80 percent of the public in favor of adding recycled wastewater to the drinking supply. After the rains came, people changed their minds.

"It's like a kid with three types of food on his plate," says Snape. "If he doesn't have to eat the one he doesn't like, why would he?" An antiwastewater campaign by the pungently named "Citizens Against Drinking Sewage" played on people's fear of "poo water" in public rallies, blog posts, and letters to the editors of major newspapers. The group sent out a half million copies of a glossy pamphlet called "Think Before You Agree to Drink." Bottled water sales soared.

SOUTH EAST QUEENSLAND ENGINEERED A DROUGHT-PROOF FUTURE FOR ITSELF, BUT ONE IN WHICH ENERGY CONSUMPTION FOR WATER HAS SOARED.

Scientists pointed out that the treated wastewater was so clean that kidney dialysis patients could drink it. Besides, they said, the water wouldn't be piped directly into people's homes but rather pumped into a storage dam, mixed with thousands of megaliters of other water, and then treated again before anyone got to drink it.

It made no difference. Bowing to public pressure, the premier of Queensland, Anna Bligh, announced that the treated water would be sent to the dams only when they fell below 40 percent. In the meantime, it would be piped to two coal power plants outside Brisbane. At that point, it was hard to justify the $2.5 billion investment in the treatment plants.

But as Queensland's population grows—about 1500 newcomers now arrive every week—the government will eventually have no choice but to use that water. It has plans for two new desalination plants, too. They may not get built for another 20 years, Dennien says, but the planning has already begun.

AND SO AUSTRALIA'S SEARCH FOR NEW water efficiencies goes on, sometimes with odd or unexpected repercussions that reveal the growing tension between energy and water resources—that gains in the one will increasingly come at the expense of the other.

Consider, for example, that over the past eight years, more than a quarter million homeowners in South East Queensland have installed rainwater storage tanks. The tanks seem like a no-brainer: Why not use the rain that falls on your roof to water your lawn or

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MOISTURE WHIP

A major hurricane releases enough mechanical energy to sustain the planet for several years. If you could figure out a way to harness and store that energy, you'd have a cheap, renewable, emissions-free power source.

Canadian engineer Louis Michaud says he can do just that. Into his Atmospheric Vortex Engine—basically a large cylindrical room—he plans to inject warm air and steam to create a whirlwind. Once it gets going, the vortex should become self-sustaining and will be used to drive a turbine. Michaud estimates that a 200-meter-diameter machine could produce 200 megawatts.

Sound too good to be true? Probably, but it's at least theoretically workable. An evaluation by a group of engineers at the Canadian Academy of Engineering damned the project with faint praise by stating that the idea "does not defy known physics." —*Sally Adee*

ILLUSTRATION: BRANDON PALACIO

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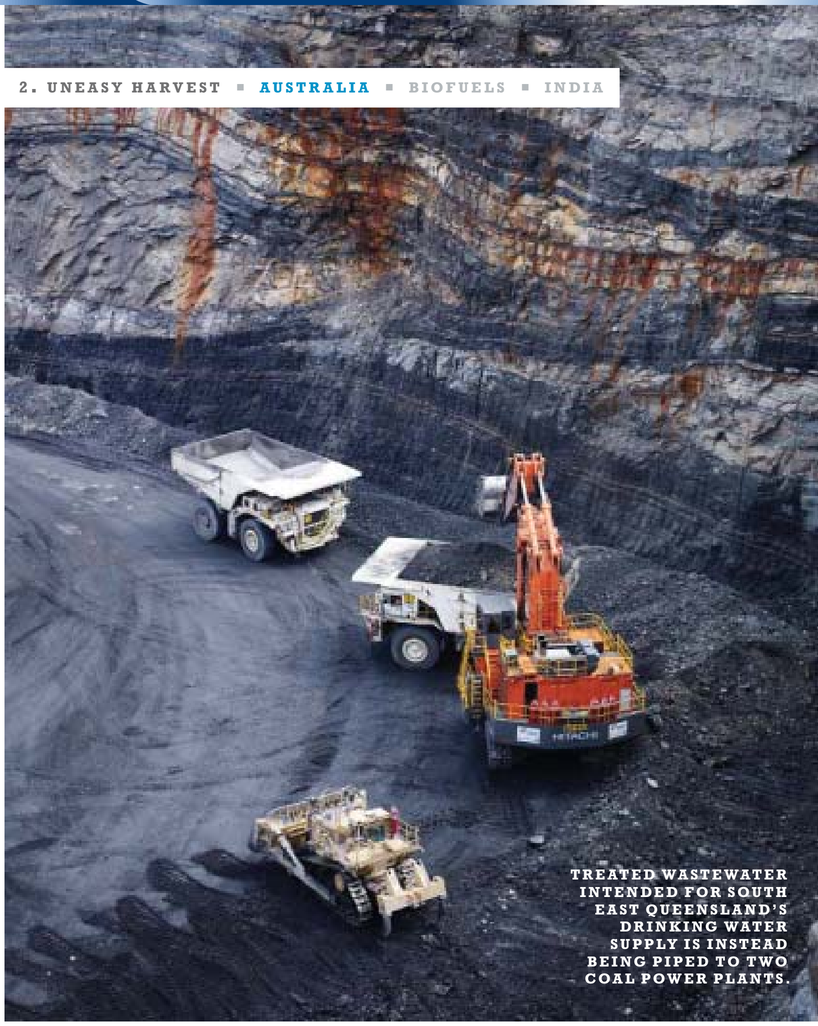

TREATED WASTEWATER INTENDED FOR SOUTH EAST QUEENSLAND'S DRINKING WATER SUPPLY IS INSTEAD BEING PIPED TO TWO COAL POWER PLANTS.

flush your toilet? With a purifier, you can even drink it. New housing developments in Brisbane are now required to install such collectors.

There's just one problem, says Ted Gardner, a scientist in the Queensland Department of Environment and Resource Management. The cheap little pumps that power the tanks use a lot of electricity. Gardner's team studied electricity usage in one posh neighborhood on the outskirts of Brisbane that touts its ecofriendly million-dollar homes. Each has an 18- to 22-kiloliter tank and an ultraviolet disinfection system.

Gardner found that the electricity used per kiloliter of water was up to 10 times as high as that for regular city water in central Brisbane; ignoring the UV system, it was still three times as much. The reason, of course, is that a single huge industrial pump that moves water to thousands of customers is much more efficient than the aggregation of thousands of tiny household pumps.

"People think big things are bad things," Gardner says. "With water, big is actually efficient."

Simply maintaining those small pumps also has an energy cost. An industrial-scale pump that serves 250 000 people may get serviced four or five times a year, while a little pump might need maintenance once a year or so. Now multiply that annual repair by several hundred thousand, add in the costs of fueling and running all those service trucks, and the energy penalty is vast.

It's also true, though, that the water grid itself uses more electricity than the amalgamation of water systems that it replaced. In part that's because water is heavy, and moving 182 ML of it around every day takes energy. Desalination and wastewater treatment are electricity intensive, too. The net effect is that the average household in South East Queensland now pays about $2 per kL for water, up from $1 a few years ago. Dennien's office is working with researchers at the Queensland Cyber Infrastructure Foundation and the University of Queensland to construct a computer model that will analyze how the grid uses energy and help optimize its operation. Running the desalination and treatment plants during off-peak hours, for example, would cut electricity costs.

For South East Queensland and indeed for the entire country to continue to grow and prosper, people will need to recognize such trade-offs. Australia will never have all the freshwater that it wants. But maybe, with deliberate planning, bold initiative, and an eye to the future, it can have the water it needs.

"There's a lesson for all governments in this: You cannot look out just 10 years or 20 years," says Dennien. "We're looking at 50 years from now—what's the population going to be, and where's our water going to come from?" ❑

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FIRE ICE

Researchers have been studying methane hydrate for decades. The volatile substance, a combination of methane gas and water ice, exists in cold and high-pressure environments, such as Alaskan permafrost or beneath ocean sediments. Scientists estimate that the world's supply of methane hydrate could dwarf the combined energy stored in all other fossil fuels. And methane is a much cleaner burning fuel than gasoline, oil, or coal.

Extracting it is another story. Think of methane hydrate as an icy cage that traps the methane molecules inside. To release the natural gas, you either warm the substance or ease the pressure; the methane vaporizes, leaving behind a puddle of water.

Most research has focused on extracting the methane, but it turns out the water itself may have value. "The water from gas hydrates will by nature be fresh with no impurities," says Timothy Collett of the U.S. Geological Survey. A team of scientists at Sandia National Laboratories led by geochemist Jeffery Greathouse is now looking into separating methane hydrates from the salty water that surrounds them by exploiting the density difference between the salt water and the hydrate-trapped freshwater.

But the researchers will still face the same problem that's stymied scientists elsewhere: figuring out a cost-effective way to separate the methane from the water. Despite heavily funded studies in many countries, including the United States, Japan, India, and China, nobody has managed to do that. *—Sally Adee*

ILLUSTRATION: BRANDON PALACIO


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BIOFUEL'S WATER PROBLEM

Irrigating biofuel crops on a grand scale would be disastrous

BY DAVID SCHNEIDER

JEREMY NIXON/ALAMY

THE GREAT ADVANTAGE OF BIOFUEL over petroleum is that the sources of biofuel are so widely available. The geologic fates may not have endowed your corner of the world with oil or gas deposits, but just about everyone can grow plants to make fuel. Unfortunately, some of the places these crops are grown require irrigation, and when water enters the equation, biofuels are a lot less attractive than the stuff they're replacing.

Take soybeans. According to Carey W. King and Michael E. Webber of the University of Texas at Austin, the processing required to turn soybeans into biodiesel requires negligible water. But if you can't depend on rain, raising the crop in the first place takes buckets. On average in the United States, 28 liters of irrigation water are needed to produce enough soybeans to propel an average vehicle 1 kilometer (12 gallons of water consumed per mile driven). Ethanol produced from corn grown on irrigated fields is almost as bad. Driving a typical flexible-fuel vehicle on E85 (85 percent ethanol fuel) produced from irrigated cornfields consumes about 26 L/km on average, assuming both the corn's seed and stalks are transformed into ethanol.

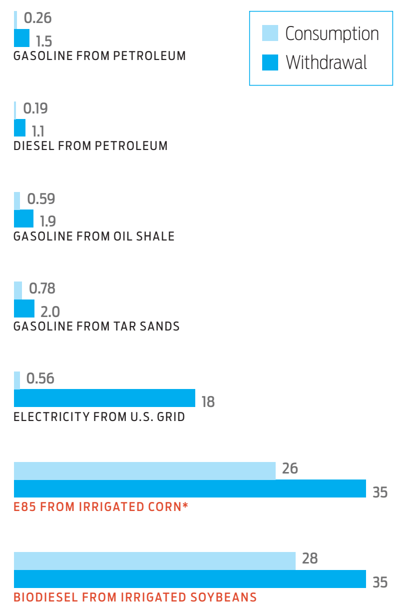
At present, less than 20 percent of the corn grown in the Midwestern corn belt of the United States is irrigated. But the increases in corn production appear to be in areas where irrigation is common. That's a problem, because irrigation already accounts for 37 percent of the water withdrawn from aquifers, lakes, and rivers in the United States (about the amount used in energy production).

Now let's look at the water involved in the production of conventional petroleum fuels. According to King and Webber, whether you use gasoline or diesel in your car, driving it a kilometer takes less than 0.33 L of water. Even that very modest estimate "could be overly pessimistic about freshwater consumption," says King, because it doesn't take into account that some of the water used to boost oil recovery is extracted from oil wells themselves.

Even the more problematic sources of petroleum—tar sands and oil shale—don't consume all that much water. True, you need high-temperature steam to separate the petroleum from the rock it's found in. But according to King and Webber, the processing of tar sands into fuel consumes on average just 0.78 L/km of water, and the processing of oil shale takes even less: 0.59 L/km.

Judged on a water-use Richter scale, then, petroleum extraction and processing make for mere tremors, whereas corn- or soybean-based biofuels can amount to building-leveling quakes. In their latest study (with Ian Duncan, published this past February), King and Webber suggest that by 2030 about 8 percent of

AVERAGE WATER REQUIREMENTS FOR DRIVING
(Liters of water per kilometer driven)



Consumption is the amount of water taken from a source that evaporates away or cannot otherwise be returned to its source. Withdrawal is defined as water that is removed from the ground or diverted from a surface-water source for use, some or all of which may be returned to that source.

** Using the whole plant.*

Source: Carey W. King and Michael E. Webber, "Water Intensity of Transportation," Environmental Science & Technology, *Vol. 42, no. 21, 2008, and King (personal communication)*

U.S. freshwater consumption might go toward making biofuels.

A better idea is to use crops that don't require any more water than what local rains provide. Oil palms in Indonesia and sugarcane in Brazil are already being used to produce biofuels in large quantities without irrigation. It's not that these plants don't need lots of water; it's just that the tropical lands they are grown on receive abundant rains. Indeed, it might make more sense to import biofuels from such water-rich regions of the globe than to try to grow them where there's not enough water. One thing's for sure: The future of any crop now being touted as a good source of biofuel will hinge on how it slakes its thirst. ❑

ILLUSTRATION: BRANDON PALACIO

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URANIUM FROM SEAWATER

The world's oceans contain about 4 billion metric tons of uranium, a thousand times as much as is available in all the world's mines. But that nuclear-power treasure trove exists in concentrations of just 3 parts per billion. Retrieving it and separating it from all the other parts has been impractical, to say the least.

Researchers in several countries, including Japan and India, think they've figured out a way to get their hands on that watery uranium: by harvesting it, literally. In Japan, the Mitsubishi Research Institute has proposed genetically engineering seaweed that will selectively absorb the heavy metal. When the plants are mature, they'll cull them, dry them, and extract the uranium. What to do with the leftover seaweed? Turn it into biofuels, of course!

The Japan Atomic Energy Commission, meanwhile, has engineered a synthetic polymer that adsorbs uranium, trapping the substance as the water flows through. After pickling a long, braided tendril of the uranium-catching fiber for 30 days, researchers were able to capture 1.5 grams of yellowcake uranium in every kilogram of the fiber.

Some major stumbling blocks remain, including the energy needed to remove the uranium from the seaweed and the recyclability of the synthetic fibers. And not everyone is convinced the method will work. The French Atomic Energy Commission, which had been collaborating with India on uranium harvesters, recently bailed out. *—Sally Adee*

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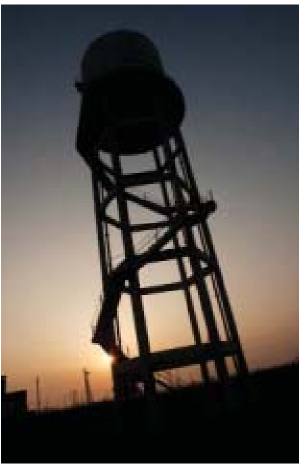


PUMPING PUNJAB DRY

Cheap energy endangers India's ability to feed itself

BY SEEMA SINGH
PHOTOS BY SEPHI BERGERSON

THE NORTHERN INDIAN STATE OF PUNJAB is the country's historic breadbasket, and 60-year-old Harnek Singh is one of the million farmers who work its soil. On a sunny February afternoon in Khunimajra, about 275 kilometers from New Delhi, he is busy repairing his tube well. The tube well is simple: a steel pipe bored into the ground and attached to a cheap electric pump. This rudimentary tool is the engine of Singh's success as a farmer. But it and millions of others like it are quickly draining away India's agricultural riches.

In dirt-covered shorts and an undershirt, Singh squats amid the thick foliage that feeds his 50-odd cattle, preparing his pump for the day's most critical event. He's about to get the 4 hours of free electricity that lets him extract water from a natural reservoir 82 meters underground. These days, that hardly suffices. He needs another 8 to 9 hours of power to finish watering his wheat and rice. So he'll continue to run the pump with diesel generators, which cost him US $4.50 an hour in fuel—a crushing price, considering that his farm's annual revenue is just $20 000. "Sometimes the [grid] electricity goes off after 2 or 3 hours, and I want to commit suicide," says Singh.

Even so, farmers are emptying Punjab's aquifers at an alarming rate. Each year, as the groundwater table steadily retreats, they are forced to go half a meter deeper to pump water. Two abandoned wells on Singh's farm offer proof of the changing conditions.

HARNEK SINGH ON HIS FARM IN PUNJAB, INDIA [*top*].

A FARMER'S PLAN FOR A DEEPER WELL; HARNEK SINGH'S TUBE WELL; A WATER TOWER IN A WHEAT FIELD [*bottom, from left*].

If cultivation continues here as it has, the groundwater—the source of most of Punjab's irrigation—could be exhausted in 20 years, say researchers at Punjab Agricultural University, in Ludhiana.

The situation is not unique to Punjab. Collectively, India's farmers extract about 212 million megaliters of water each year to irrigate some 35 million hectares. That amount of water—enough to submerge London by more than 100 meters—is considerably more than what flows into the aquifers through rainfall and runoff, and plummeting water tables now plague other areas as well. Based on its aquifers' natural rate of recharge, Punjab can sustainably support at most 1.8 million hectares of rice, according to the state's director of agriculture, Balwinder Singh Sidhu. At present, it has 2.8 million hectares of rice. If the situation doesn't change, a food crisis in India seems imminent.

A main culprit is grossly underpriced electricity. For decades, it's allowed farmers to pump groundwater at very low cost. Now, not only is the water running out, but India's electricity utilities lack the revenue to maintain their infrastructure and provide rural communities with adequate power.

IT'S ODD TO EVEN BE TALKING ABOUT India's faltering agricultural sector, because in so many ways the Green Revolution that began in the mid-1960s has been a magnificent success. As the country's farmland grew tenfold, India went from frequent famines to food self-sufficiency, even as its population more than doubled.

Punjab is important to India's ability to feed itself. Despite its small size, it accounts for about a fifth of the country's wheat and more than a tenth of its rice. What's more, its productivity has grown by an order of magnitude, to 11.5 metric tons of rice and wheat per hectare, the highest output in the world, says G.S. Kalkat, the chairman of the Punjab State Farmers' Commission. But because nearly all the state's farmland is irrigated, this agricultural bonanza has come at the expense of the state's groundwater.

How did unrealistic electricity pricing make that happen? India's electricity grid is largely controlled by about 20 state boards. The first of these was created in 1948, to move the control of power generation away from private operators. But the boards never managed to operate in good financial health, and grid infrastructure began to deteriorate. Soon enough, power shortages became routine.

In the mid-1970s, state governments began to shift to a system of low, flat electricity tariffs for farmers, on the premise that the utilities' profits from the agricultural sector were too small to justify the cost of installing electricity meters. But as the agricultural revolution gained momentum, groundwater use shot up, while electricity rates remained flat. Several states, including Andhra Pradesh, Madhya Pradesh, and Maharashtra, as well as Punjab, went even further and made power free for farmers. The politicians in these states viewed the move as an easy way to bolster their populist credentials and gain rural votes.

Only recently did that arrangement begin to change. Under pressure from the World Bank and the Asian Development Bank, a few states scrapped free power in 2005 and reverted to a system of subsidized pricing. But not Punjab, which continues to dole out free electricity.

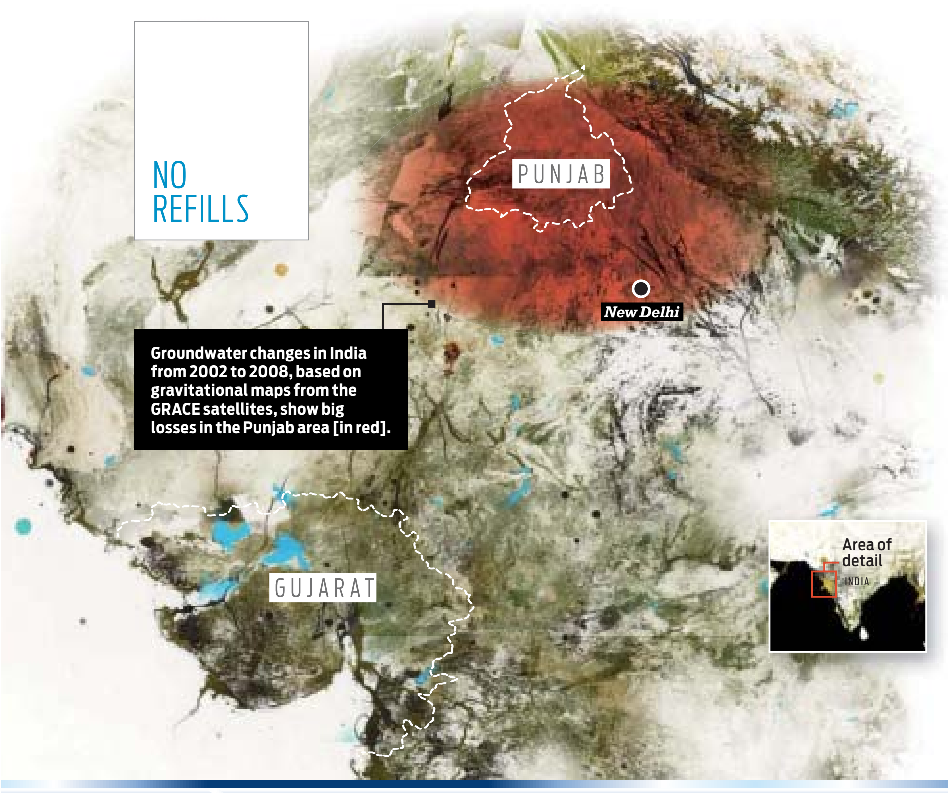
As farmers' electricity use grew in Punjab, the quality, reliability, and supply of that electricity all declined. Back in the 1980s, farmers could expect 18 hours of electricity a day; now it's at most 6 hours. And because the groundwater table has been falling at about half a meter each year, farmers actually need more energy every year to irrigate the same field. Though Punjab authorities aren't doing the math themselves, a back-of-the-envelope calculation shows that raising the 8 ML needed to irrigate one hectare of rice by an extra half meter requires at least an additional 11 kilowatt-hours each year. (That's the energy needed to lift nearly 30 empty Airbus A-380s.) India's Central Electricity Authority has estimated that electricity demand will outstrip supply in Punjab by as much as 28 percent this year.

G.S. KALKAT, CHAIRMAN OF THE PUNJAB STATE FARMERS' COMMISSION, HOPES WATER CONSERVATION WILL WORK.

INDIA'S ELECTRICAL FAILINGS AREN'T really the farmers' fault, of course. A third of the nation's installed capacity of 157 gigawatts gets lost in the system, either from technical problems in the transmission and distribution systems or from theft. Even in the states with relatively well-run grids, less than 65 percent of electricity use is metered. Many Punjab farmers are now clamoring for metered electricity, which would be cheaper than running a diesel generator. "No farmer has demanded free power," says Singh, the farmer in Khunimajra. "Please charge [for it] and give us an assured supply."

Though some farmers agree with Singh, clearly others do not. Traditionally, electricity has been viewed as a social benefit rather than a service to be paid for. Those politicians who've tried to change the system haven't fared well. When he was chief minister of the southern state of Andhra Pradesh, N. Chandrababu Naidu introduced metering; he was ousted in the next election. Cases like Naidu's cause Tushaar Shah, a researcher at the International Water Management Institute, based in Colombo, Sri Lanka, to wonder whether the Punjab farmers are in earnest. "Many people have told me that Punjab farmers want metered power supply," he says. "But I am not sure they will be will-

NO REFILLS



Groundwater changes in India from 2002 to 2008, based on gravitational maps from the GRACE satellites, show big losses in the Punjab area [in red].

ing to pay 4 to 5 rupees [$0.09 to $0.11] per kilowatt-hour for a 24-7 metered power supply."

THOUGH PUNJAB FALTERS, THE COASTAL state of Gujarat has managed to overcome similar circumstances. As in Punjab, flat electricity tariffs in Gujarat led to mounting financial losses for the state electricity board and the rapid depletion of aquifers. It also spawned an informal water market in which tube-well owners sold surplus water to poorer farmers who couldn't afford tube wells or couldn't get permission to install them.

In 2003, Gujarat's state officials came up with a plan to improve the power supply in rural areas and curb groundwater consumption. A $254 million parallel rural transmission network was laid across the state, with feeders for supplying agricultural users separated from those going to commercial and residential users. Tube-well owners now pay the market rate for full-voltage power for 8 hours a day—just long enough to irrigate an average-size field, the state's regulators figured. Experts say the scheme has cut groundwater pumping on medium and large farms. The farmers have benefited, too: Continuous and full-voltage power means less wear and tear on the tube wells' electric motors.

What's more, villages in Gujarat now have electricity around the clock, of a quality seldom seen in rural India. Access to reliable electricity has in turn led to a better drinking water supply and improved street lighting; rice and flour mills, telephone exchanges and kiosks, and computer-training centers are thriving. A study of 55 villages by the International Water Management Institute in 2008 concluded that the scheme had managed to cap groundwater withdrawal in a fair manner.

But not everyone has prospered. The state's small tenant farmers, who relied on the informal water market to irrigate their crops, have largely been cut out of the new system, according to a survey by the Columbia Water Center India (part of the Earth Institute of Columbia University, in New York City). To assist those poorer farmers, the state government is subsidizing new tube-well connections, which previously it had banned, says Shah, who headed the International Water Management Institute's study. In the last three years, the state has issued 200 000 new connections, he says, mostly to small farmers.

"Gujarat has more or less resolved the energy-water nexus to the extent it is resolvable," Shah says.

GUJARAT'S EXAMPLE PROVES THAT reform can work. But Gujarat may not hold all the answers for Punjab, says Kalkat, the chairman of Punjab's farmers' commission. He worries about the effect of metering on Punjab's small farms—how will they pay for their electricity? Kalkat favors alternatives that avoid the thorny politics of electricity pricing.

Some of these alternatives are already reducing water use. Two years ago, Punjab passed a law that sets a date close to the monsoon season when farmers can start sowing their fields; previously they would sow much earlier and thus pump more water. Groundwater data shows that the law has had some benefit, says Sidhu, the state's director of agriculture. Punjab is also introducing new varieties of rice that grow faster and use less water.

To trim water use further, the state agriculture department is now helping farmers laser-level their fields. Farmland that isn't flat requires as much as 25 percent more water. Using lasers attached to high-power tractors, workers can measure the terrain and then scrape away the excess grade. As of last June, Punjab had about 700 laser levelers operating. As a result, some farmers have largely been able to stop using groundwater for irrigation.

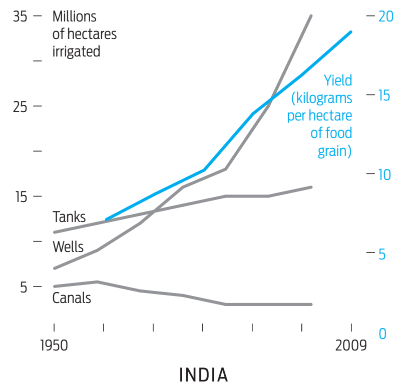
Kamal Vatta and Rupinder Singh Sidhu, professors at the Punjab Agricultural University, say that the water savings could go much further if state subsidies were revised to favor less-thirsty crops. At present, they say, incentives for growing rice essentially pay for the entire cost of extracting groundwater, including the diesel generators. As a result, farmers feel no pressure to shift to crops such as corn, which requires a quarter of the water needed for rice but commands a much lower subsidy.

Whether water conservation and agricultural policy will be enough in Punjab or whether, as in Gujarat, a new electricity infrastructure is needed might not be clear for some time. At the rate Punjab's groundwater is disappearing, time is something India may not have enough of. ❑

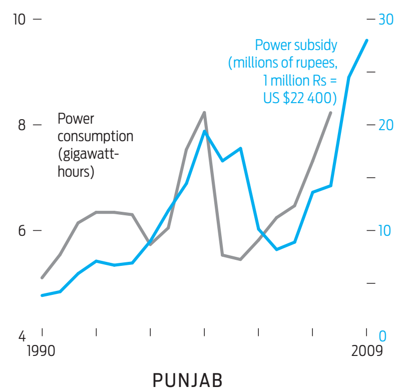
GREEN REVOLUTION

India's yield of grain has nearly tripled as it has irrigated more land using groundwater from tube wells. How much electricity farmers use for pumping the groundwater roughly follows the rate of electricity subsidies.

Grain grows with groundwater...



Power matches the money



Sources: Grain growth: Department of Agriculture and Cooperation, New Delhi; World Bank report "Deep Wells and Prudence: Towards Pragmatic Action for Addressing Groundwater Overexploitation in India." Electricity: Punjab State Electricity Regulatory Commission. Data compiled by professors Kamal Vatta and Rupinder Singh Sidhu

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3 TINY TEST BEDS

SINGAPORE ▪ MALTA

SINGAPORE'S SKYLINE GLEAMS BEHIND THE MARINA RESERVOIR. THE NEWLY ENCLOSED BAY IS FLANKED BY A THREE-PILLARED RESORT BUILT ON RECLAIMED LAND.

SPECIAL REPORT ▪ WATER VS. ENERGY

WIZARDS OF THE WATER CYCLE

Singapore's toilet-to-tap technology has saved the country from shortages—and a large electricity bill

BY SANDRA UPSON
PHOTOS BY DARREN SOH

SINGAPORE BEGAN ITS JOURNEY to sovereignty with a mighty jolt. The island was still an exotic outpost of the British Empire when World War II delivered the shake-up. Japan's army was preparing to invade from the Malay Peninsula, and the British forces beat a retreat to Singapore across the one bridge connecting it to the mainland. To thwart the Japanese troops, the Royal Engineers blew up the bridge behind them.

The blast sealed the island's doom, for it also ruptured a critical pipeline that brought water from Johor, a Malay state. The people of Singapore discovered they had only a few days' water stored in their meager reservoirs. The island was truly defenseless. The Japanese swiftly repaired the bridge, bicycled across the strait, and claimed victory.

Sixty-eight years later, this port city has both gained territorial independence and managed to bootstrap its way to wealth in spite of a lack of water and energy. And now, against all odds, complete water independence—from both Malaysia and even the weather—is within easy reach. Rather than flushing waste into the sea, the water utility collects the country's wastewater, cleans it to pristine levels, and returns it to the public supply. Singapore has thus short-circuited the water cycle by reducing it to an island-ringing loop.

At first, no one relished the idea of drinking wastewater. Rejuvenating the waste stream requires electricity to power an intensive cleaning process, and that investment makes the recycled water more expensive than what's used by cities blessed with nearby freshwater lakes, rivers, and aquifers. But presented with a set of tough choices, Singapore chose water recycling—and so far it has worked admirably.

WHEN SINGAPORE FINALLY SEPARATED from Britain and then Malaysia in the 1960s, water was at the top of the agenda. The government negotiated two treaties with its mainland neighbor to guarantee a water supply, at a cost, for the next century.

With a base supply in place, the water utility went looking for more. The agency started with the one resource available to this tropical dollop of land, its ample rainfall—some 237 centimeters a year. It built dams to interrupt the flow of its streams and tiny rivers and built 15 reservoirs to store rain. Such reservoirs are crucial because they stand in for the groundwater that Singapore lacks.

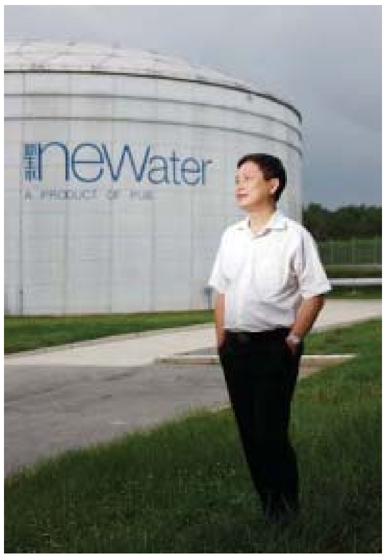
REVERSE-OSMOSIS MEMBRANES AT A NEWATER PLANT, OVERSEEN BY HARRY SEAH [*top right*], PRODUCE THE NEWATER SAMPLED BY CHILDREN.

Then the utility did a radical thing. After half a decade of research and tests at a pilot recycling plant, Singapore's planners unveiled their ultimate strategy for water security. They would force wastewater through filters under high pressure to remove all microbes, viruses, and larger impurities. The utility called its product NEWater, and it called the treatment plant a factory. With great emphasis on its sparkling newness, treated wastewater made its public debut in 2003.

The real work was about to start. One by one, the utility cajoled its customers into accepting the water. Manufacturers wondered what residues the water might leave in their factories, but Harry Seah, the utility's director of technology and water quality, pointed out that NEWater was cleaner than most drinking water. "At first I had to convince them," Seah recalls. But soon enough, he had signed on the island's 12 wafer-fabrication plants and other electronics manufacturers, and the utility laid dedicated pipes to deliver NEWater. Now Systems on Silicon Manufacturing Co., which uses ultrapure water to wash its silicon wafers, champions NEWater.

NEWater TASTE TEST

Three choices: NEWater, bottled water from Malaysia, and a glass filled at the tap. Your correspondent sat down to drink. The NEWater was bland to a fault, like paper made potable. The Malaysian water delivered a cloying aftertaste—a perplexing blend of dryer lint and berries. The drink from the tap, however, was just right.



The company calculated that the recycled water's exceeding purity saves it more than half a million dollars a year, in part by cutting out steps in its internal water-purification process.

Singapore also started priming the public. The prime minister drank a bottle of NEWater at a national festival, and the crowd cheered. The subtext was clear—patriotic Singaporeans drink wastewater. But the rest of Singapore was slower to follow. A parody of a popular nationalist song, "Count on Me, Singapore," cheerily urged residents to "Drink Our Pee, Singapore."

The queasy reactions of some Singaporeans didn't deter the utility, which built four more wastewater treatment plants and is about to increase its NEWater production to 555 megaliters a day. By the end of this year the plants will treat enough sewage to cover nearly a third of Singapore's water needs.

For now, only a tiny fraction of the drinking supply is NEWater. About 40 ML are blended in with the city-state's potable water each day, equivalent to 2 percent of consumption. The utility also built a seawater desalination plant that produces 136 ML of water each day, or a bit less than one-tenth of Singapore's supply. The city-state has all the water it needs.

NATURE'S HYDROLOGICAL CYCLE RELIES on sunlight to evaporate water, leaving behind salt and other impurities and returning freshwater to Earth in the form of rain and snow. But it can be capricious: Most freshwater evaporates from the oceans, where it rises through the atmosphere and then cools to form clouds. Winds push around the clouds, driving a few of them over land, where they deposit a mere tenth of the world's precipitation, according to the U.S. Geological Survey. Singapore decided to cut the atmosphere out of the transaction and to replace evaporation with speedier mechanisms—membranes.

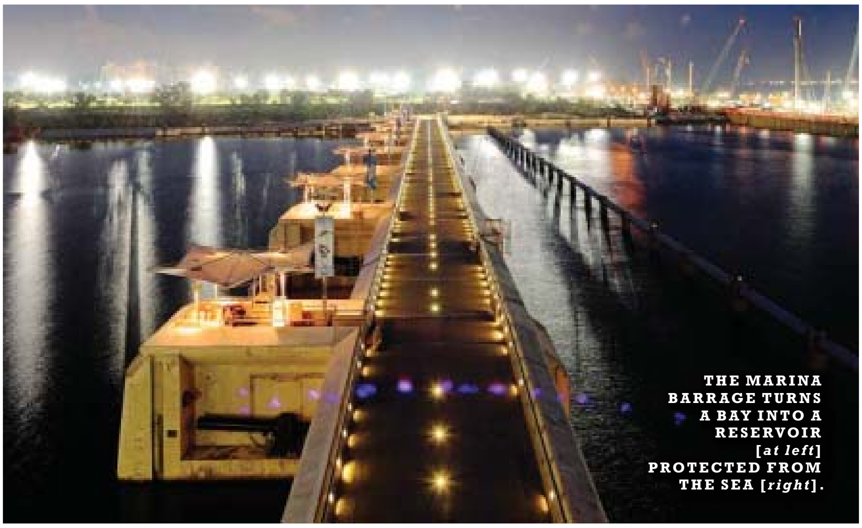
Here's how it works: First, a treatment plant gathers up the city's used water and separates out the large, easily removable impurities. About 60 percent of the water is released into the sea. The rest gets sent to a NEWater factory. The water enters contaminated with bacteria, viruses, and all sorts of carbon-based particles and emerges cleaner than what flows from just about any tap in the world.

The main tactic of the water trade is to simply push water through tiny holes—the smaller the holes, the fewer the undesirable molecules that can sneak through. The art is to do so without sending the electricity bill skyrocketing or clogging up the tiny holes with grime. Here, the first step is to force the water through a membrane that blocks particles of up to 0.2 micrometers in size, catching most bacteria and protozoa. The membrane looks like a cylinder filled with skinny, hollow tubes. The stream flows into the porous straws. Water molecules push through the pores and collect outside the membranes, while the larger particles continue traveling inside the tubes, to be disposed of separately.

The water still needs to be stripped of any viruses that might be adrift in the flow. For this the partially treated stream needs a reverse-osmosis membrane. In one configuration, paperlike sheets of membrane more than a meter long are sandwiched between sheets called spacers. The stack of membranes and spacers is wound up into a cylinder, like a thick roll of wrapping paper. The core of the cylinder is an empty channel where the clean water collects.

As the stream is pushed into one end of the roll, the impurities slide along the spacers and never penetrate the polymer membrane. The water molecules, however, escape through the 0.0001-µm pores and slip into the central channel.

These two steps remove just about everything, but in a third and final step, mercury lamps generate ultraviolet-light rays that penetrate the water. The radiation scrambles the genetic material of any bacteria and other microorganisms that


THE MARINA BARRAGE TURNS A BAY INTO A RESERVOIR [*at left*] PROTECTED FROM THE SEA [*right*].

might have slipped through, destroying their ability to reproduce. Now the water is ready for the tap.

THE SIGNIFICANCE OF NEWATER IS MUCH greater than its literal contribution in drops or buckets or liters per person. "NEWater is key to our whole strategy," Seah says.

Seah is a soft-spoken, dapper man with a face that collapses frequently into a brassy laugh. He's been with the Public Utilities Board for almost two decades, and he's seen the NEWater project through to maturity. "The real beauty of NEWater is its multiplying effect," he explains. What he means is that if the utility recycles 50 percent of its wastewater, Singapore can squeeze one more drop out of every two it desalinates or collects from the sky. "If I can achieve 100 percent recycling, I wouldn't even need rain," Seah says.

That's critical, given how few options Singapore has. Half of the island has already been converted into rainwater catchment areas, and three new reservoirs will soon bring it to two-thirds. The other source of freshwater is Singapore's one desalination plant, which consumes so much energy it can cover only a fraction of the overall demand.

Consider the details. To remove salt from seawater, Seah says the treatment plant must apply a pressure of about 7 megapascals. To remove impurities from wastewater, he requires less than 1 MPa. That translates directly into the energy cost for the whole plant—more than 4 kilowatt-hours per thousand liters of water for seawater desalination, versus 0.7 kWh for NEWater. "It's a no-brainer," says Seah, and his eyes crinkle into a laugh. "Win, win, win!" he says.

Asit Biswas, an international water-policy expert who splits his time between the National University of Singapore and the Third World Center for Water Management, in Mexico, sees Singapore as one of the few places where the water authorities agree with his own controversial position—that water scarcity simply does not exist. What does exist, just about everywhere, is bad water management.

The problem, he says, is that people tend to assume that water is like oil or any other fossil fuel and that it behaves according to the same basic economic principles. "But water is not oil," he says. "Once we use oil, it breaks down into various components. You can't put it back together." Water, despite its tendency to evaporate and trickle out of reach, doesn't change its molecular structure. "There is no limit to how many times water can be reused," Biswas points out.

That simple fact radically changes the way that water is counted. What's available to a city or country is not just a matter of how much ice sits in a Himalayan glacier or how much rain falls during monsoon season. Suddenly, Singapore is water rich. The water that falls from the sky may have once washed the streets of Paris or filled Cleopatra's bathtub. Now it's augmented with some of the water used by Harry Seah, Asit Biswas, and everybody else in Singapore. The utility isn't waiting for nature to turn its used water fresh again—it's letting technology do the job.

NOT EVERYONE CAN BE CAJOLED INTO drinking recycled urine. In Queensland, Australia, and in San Diego, public opinion has thwarted local utilities' water-recycling ambitions. But at least three sites in the United States—Scottsdale, Ariz.; Orange County, Calif.; and northern Virginia—purify wastewater and blend it into their drinking water.

In fact, most places reuse water—just without meaning to do so. According to Peter Gleick's *The World's Water 2002–2003*, each drop in the Colorado River is used 17 times. Similarly, residents of London drink water that was discharged from numerous wastewater treatment plants upstream on the Thames.

In Singapore's case, the deliberate reuse of water has played a prominent role in the country's development. Seetharam Kallidaikurichi is the director of the Institute of Water Policy at the National University of Singapore, and he argues that Singapore's water strategy has been the foundation of the country's economic success in the last 45 years. "The evidence is beginning to emerge," he says, "that it's not water among many other things but water as central, the key to unlocking the vicious cycles of deprivation and poverty into economic success and a good quality of life."

But prioritizing water means using a considerable amount of energy to make it, clean it, and move it. The question is how to optimize the juggle of resources. Because Singapore must import some 290 billion cubic feet of natural gas to run its power plants, it can be said that the country has merely substituted one form of dependence for another.

The consequences of that dependence are starting to hit home. Darren

Sun, an associate professor of civil and environmental engineering at Nanyang Technological University, in Singapore, has seen an uptick in interest in his work on energy-efficient membranes. “In most water engineering, people didn’t care about how much energy goes in—until recently. The energy crisis made this a critical issue,” he says. Sun is investigating a membrane design that uses titanium-dioxide nanofibers to filter water and generate electricity simultaneously.

But the research is far from mature, so for now the energy cost will remain high. That’s the price Singapore must pay for a first-rate water supply and a healthy country, says Kallidaikurichi. “You may argue that water here consumes more energy, but the city needs more water, because it’s the city that’s producing more wealth.”

The solution to making the trade-off work, say Biswas and Kallidaikurichi, is purely economic: Singapore charges all its customers the marginal cost of water—that is, the cost of producing another liter. For Singapore, that means desalination. So the Public Utilities Board has set the price of water to pay for its energy-intensive operations.

As a result, the utility has enough cash to investigate new technologies. Seah would like to cut the energy needed for desalination by more than half, to 1.5 kWh per thousand liters, and the energy for NEWater to 0.4 kWh from 0.7 kWh.

He’s optimistic. After all, the NEWater processes would have consumed more energy per liter had his engineers not experimented with them. “The technologies came from everywhere, but I think our value is in how we exploit them,” Seah says. “How we put them together. How we wrote the software. How we operate the plants.”

For example, he and his colleagues found a way to introduce a bit of chloramine, a disinfectant, into the membrane-filtration process. That addition prevents the pores from clogging without degrading the membrane material—a challenge that had stymied the industry for some time. Clogged pores mean more pressure to drive the water through, with a larger electricity bill as a result. Similarly, the utility’s engineers have found a way to use less pressure in operating a membrane bioreactor, a machine containing swarms of microorganisms that snack on contaminants in the water. That innovation will soon replace the first filtration step, making NEWater about 20 percent cheaper to produce, Seah says.

Other innovations are likely to trickle out of Singapore’s water sector, as companies and academics seek to profit from the water utility’s interest in innovation. For example, researchers under Say Leong Ong, acting head of the environmental sciences and engineering division at the National University of Singapore, are figuring out the mechanisms used by mangrove trees and tilapia fish to process the salt in seawater, with the hope of one day designing membranes that mimic nature.

Ultimately, Singapore will have true water security only if it can reduce its dependence on imported energy. A civilization’s surplus energy, arising from its trade and technological prowess, is what allows an economy to shift investment away from life-critical needs such as water to education, art, and a rich civic life. An energy-secure water sector, then, will be a major question for the next 50 years of the tiny island’s nationhood. ❑

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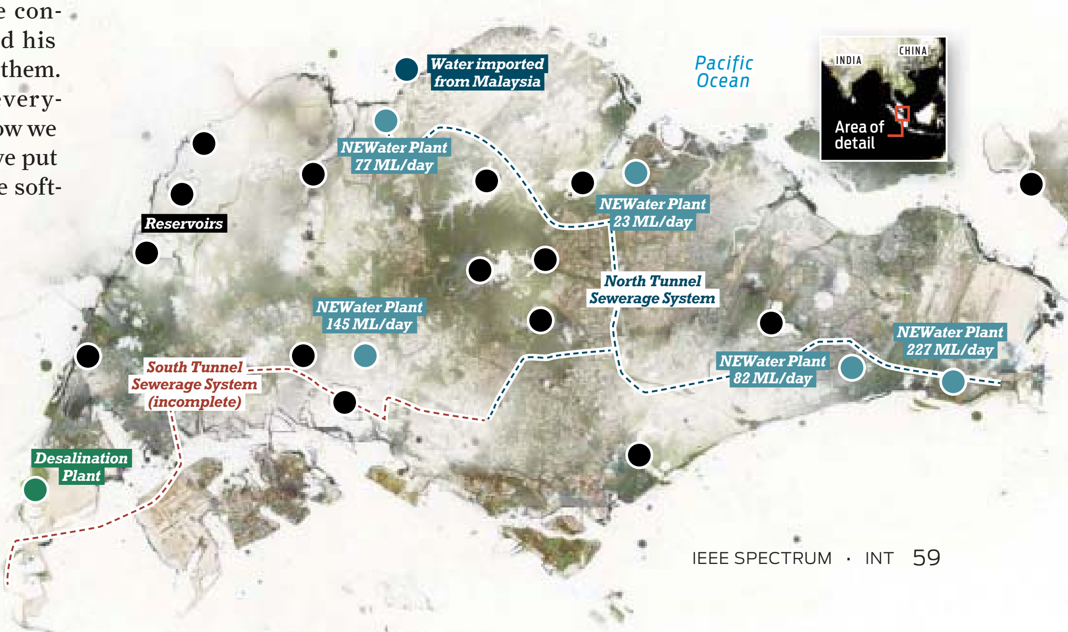
FREE ENERGY? URINE LUCK!

You may not think of urine as a valuable resource—quite the opposite, probably—but Ohio University chemical engineer Gerardine Botte has come up with a way to harness it for good. Botte’s technology efficiently produces hydrogen for fuel-cell-powered cars, from urine.

Dry out that urine and you’re left with a compound called urea, a single molecule of which contains four hydrogen atoms. The bonds that bind urea’s hydrogen are much easier to break than the hydrogen bonds in water, which is typically used as the source for hydrogen in fuel cells. Experimenting with human urine, Botte showed that applying a mere 0.37 volt did the trick, much less than the 1.23 V required to split water. What’s more, urea yields twice as much hydrogen per molecule.

Botte’s research might lead to cheaper hydrogen for fuel cells as well as cheaper wastewater purification: A scaled-up version of the technology could generate hydrogen while treating sewage. *—Sally Adee*



NOT JUST TOILETS... NEWater plants and reservoirs dot the island, providing an engineered stand-in for the groundwater Singapore lacks.

ILLUSTRATION: BRANDON PALACIO; MAP: ANDREW ZBIHLYJ

THE SALINE SOLUTION

Desalination takes too much energy, but emerging technologies will help

BY SALLY ADEE
ILLUSTRATIONS BY EMILY COOPER

DESALINATION—removing dissolved minerals from seawater, brackish groundwater, or treated wastewater—appears at first glance to be the ideal answer to freshwater shortages. What could be more attractive than harnessing the planet's seemingly inexhaustible 1.34 quadrillion (that's 15 zeros) megaliters of seawater? Oceans are drought-proof. In theory, so is wastewater.

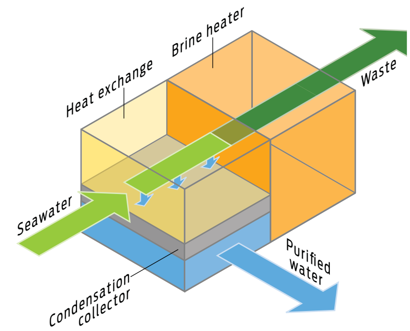
In the Persian Gulf, where seawater normally contains a lip-puckering 45 grams of salt per liter, thermal desalination is king. This method vaporizes water to purify it. Pretty much everywhere else, desalination is done by reverse osmosis, which purifies water by forcing it through membranes. Both methods cut down the salt to a drinkable 0.5 gram per liter.

But there's a price. As long as the cost of desalination continues to depend on the cost of energy, these technologies won't help much of the energy-starved developing world that needs them the most. And desalination isn't just energy intensive; there's also the problem of the toxic sludge it leaves behind. In this business, brine—the concentrated result of purifying water—might as well be a four-letter word. Throwing the brine back into the ocean can kill fish and smaller denizens of the food chain.

Several contenders might make history of these concerns. New methods in the pipeline reduce desalination's energy demands in innovative and intriguing ways. Further off are technologies that could turn desalination's Achilles' heel into a source of strength: In the future, desalination might just be powered by the very stuff it filters out. ❑

Today

BRUTE FORCE: THERMAL DESALINATION



HOW IT WORKS
Boil seawater, condense the vapor, and drink the result.

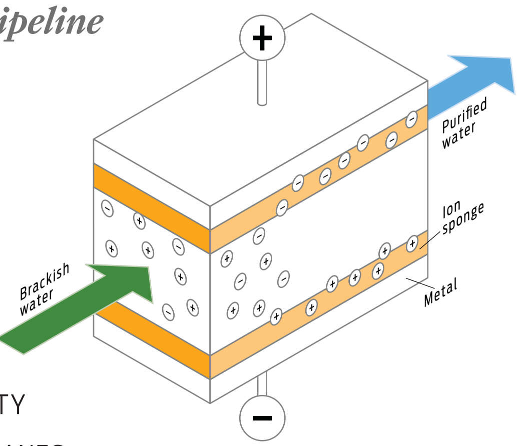
UPSIDE
Pure water no matter what the feedstock is.

DOWNSIDE
Energy intensive, enormous infrastructure, toxic brine waste.

BEST FOR
Ocean water. The energy required is the same regardless of the water's salt concentration, so the process is well suited for highly saline waters.

ENERGY TRADE-OFF
Evaporation and pumping can consume up to 80 megawatt-hours per megaliter of water produced. Its use is largely confined to the Middle East, where plants

In the Pipeline



ZAP 'EM: ELECTRICITY INSTEAD OF MEMBRANES

HOW IT WORKS
Capacitive deionization works without membranes. It filters impurities by streaming the water between two charged electrodes. The electrodes attract ions in the water, which stick to them, leaving freshwater. The attached ions eventually clog the electrodes, but cleaning is easy: Simply reverse the electrical polarity to flush the ions back out. Good candidates for electrodes are advanced materials such as carbon aerogel and mesoporous carbon.

UPSIDE
Easy to clean; requires less power. The process could theoretically go on forever without changing electrodes.

DOWNSIDE
Works only for brackish water; in practice, electrodes can foul. Does not mitigate toxic brine.

BEST FOR
Brackish water.

ENERGY TRADE-OFF
Far less pressure means less energy.

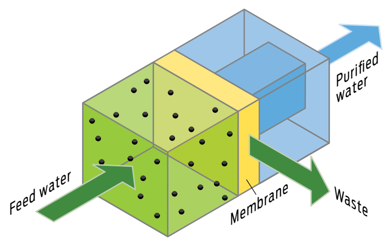
WHAT'S NEXT
This year, a test reactor will be unveiled in New Mexico, part of an international project led by Campbell Applied Physics, in Rancho Murieta, Calif., and several U.S. national laboratories.

tend to use waste heat from adjacent power plants and cheap oil instead of electricity. Thermal desalination is not used in the United States: The typical U.S. energy price of $0.065 per kilowatt-hour translates to $5200/ML of water. At less than half a cent per liter, that's cheap enough for bathing and drinking, but for irrigation or industrial uses, the price tag is staggering.

WHAT'S NEXT

Saudi Arabia's Shoaiba, an 880-ML-per-day power and desalination plant on the Red Sea, is the largest thermal desalination plant in the world. But even for seawater, the market-research firm Lux predicts, thermal desalination will not extend past the Middle East, which has the lion's share of cheap oil to desalinate its very salty water.

PUSH!
REVERSE OSMOSIS



HOW IT WORKS

Separate saltwater and freshwater with a membrane that blocks salt ions, and the freshwater rushes to the salty side by the natural process of osmosis. Reverse osmosis (RO) uses hydraulic pressure to shove water molecules in the opposite direction, with the membrane holding back the salt.

UPSIDE

Comparatively low energy cost.

DOWNSIDE

Toxic brine; can't completely filter potentially harmful substances like boron, arsenic, lithium, and some pharmaceutical compounds. When membranes become clogged, they must be scraped and bleached or they stop working; cleaning, however, reduces the expensive membranes' lifetime. Pretreating the water to remove the gunk slows the rate of fouling but requires a lot of real estate.

BEST FOR

Brackish groundwater, which contains on average only 3 to 5 grams of salt per liter. RO is also increasingly being used to desalinate seawater, however.

ENERGY TRADE-OFF

The pressure needed to push water through the membrane is proportional to the water's salinity. Higher pressure means higher energy cost. On average, RO demands at least 3.5 MWh/ML produced from brackish water and more for seawater.

WHAT'S NEXT

A Carlsbad, Calif., plant slated to open in 2012 will produce more than 189 ML of drinking water per day from the Pacific Ocean, making it the biggest RO plant in the United States.

SPIN CYCLE:
BETTER PRETREATMENT

HOW IT WORKS

A team of researchers at Palo Alto Research Center (PARC), in California, has developed a reactor that separates particulates from water by sending it through a long, curved channel. Hydrodynamic forces cause the particles to become concentrated near the inner wall of the channel, which allows for easy separation.

UPSIDE

Uses very little energy; compact; reduces the footprint of RO pretreatment.

DOWNSIDE

The channels themselves might be susceptible to fouling. Does not address desalination's toxic brine output.

BEST FOR

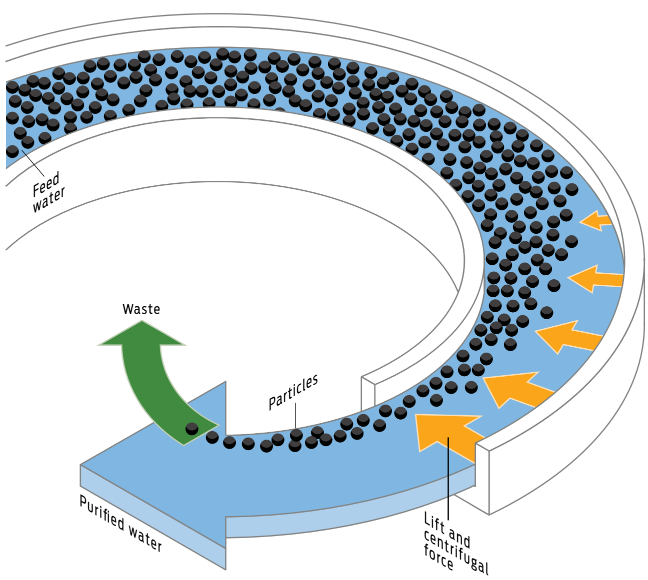
Seawater, brackish water, and wastewater.

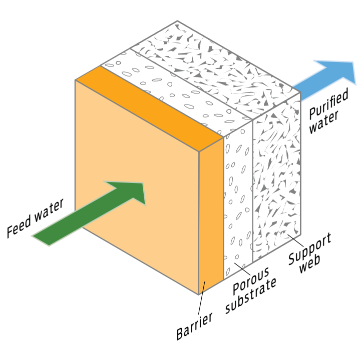
ENERGY TRADE-OFF

Unlike centrifuges, which spin contaminants out of water using *g* forces in the thousands or tens of thousands, PARC's laboratory-scale system requires *g* forces in the single digits. That reduces the energy demand of pretreatment to only 2.5 kWh/ML of water.

WHAT'S NEXT

A test reactor will be installed on a U.S. Navy aircraft carrier later this year.





BORDER PATROL:
BETTER MEMBRANES

HOW IT WORKS

The next generation of membranes will rely more on clever chemical engineering and less on brute force to push water molecules across them. Less hydraulic pressure means the new membranes would reduce RO's energy demands. At IBM Research in Almaden, Calif., researchers are working on membranes that will be at once tougher and more sophisticated, permitting only substances with proper molecular identification to cross the barrier. First on the chopping block are arsenic and boron.

UPSIDE

IBM's membranes show a 90 percent reduction in boron concentration.

DOWNSIDE

Not yet commercially available. Doesn't address the problem of toxic brine.

BEST FOR

Wherever RO is used now.

ENERGY TRADE-OFF

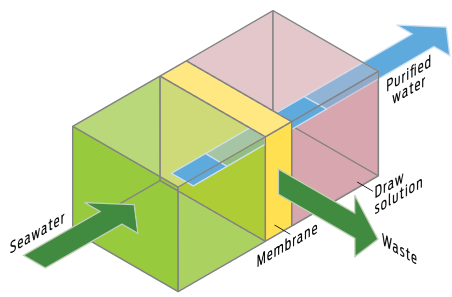
Membranes that work at lower pressure should slash RO's energy demand.

WHAT'S NEXT

In March, IBM Almaden and the King Abdulaziz City for Science and Technology, in Saudi Arabia, announced a joint effort to build a solar-powered water desalination plant using Almaden's membrane work. The plant will produce 30 ML per day.

Turn the page for Uncharted Waters

Uncharted Waters



PULL! FORWARD OSMOSIS

HOW IT WORKS

Yale University spin-off Oasys, headquartered in Cambridge, Mass., has developed a method that places seawater next to an even more concentrated salt solution, separated by a membrane. The concentrated solution, a mixture of ammonia and carbon dioxide, sucks the freshwater out of the seawater. Then heat drives off the ammonia and CO_2, leaving freshwater.

UPSIDE

Requires very little energy. In theory, the draw solution can be recycled indefinitely.

DOWNSIDE

Toxic brine waste. The ammonia solution must be completely removed from drinking water.

BEST FOR

Any salt concentration.

ENERGY TRADE-OFF

Oasys says the technology uses one-tenth of the energy required by today's RO plants.

WHAT'S NEXT

The start-up received US $10 million in investment funding in 2009 and is now working on a commercial platform.

DIFFERENCE ENGINE: OSMOTIC POWER

HOW IT WORKS

Osmosis could be the foundation of a new power-generation method. Separate two sources of water with very different salt concentrations—for example, river water and ocean water, or salty brine and nonsaline wastewater—with a thin semipermeable membrane. Water will rush to the salty side by osmosis, increasing the pressure on the salty side. The resulting pressure difference can drive a turbine and generate electricity. A Norwegian company called Statkraft is doing just that. Its engineers think osmotic power could potentially provide 1700 terawatt-hours a year. This method could even repurpose the brine waste of desalination plants.

"Desalination plants produce extremely salty water as the by-product," says Spike Narayan, IBM Almaden manager of science and technology. "So you have concentrated brine, and you have wastewater coming in with no salt. Bring them together and you can generate energy while you dilute the brine."

UPSIDE

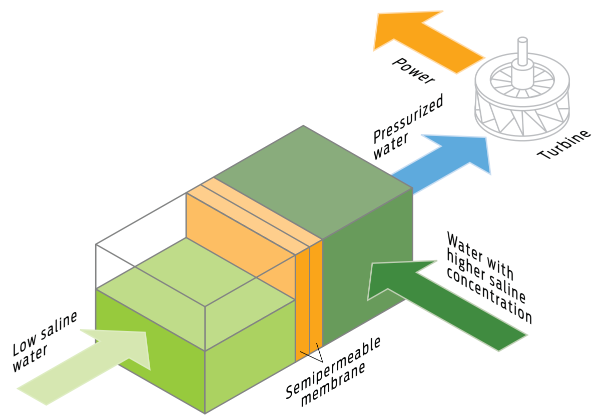
Generates electricity as it dilutes toxic brine waste.

DOWNSIDE

The pilot plant produces only enough power to run a coffeemaker.

BEST FOR

Anywhere rivers meet oceans or where desalination and wastewater treatment plants can cross their streams.

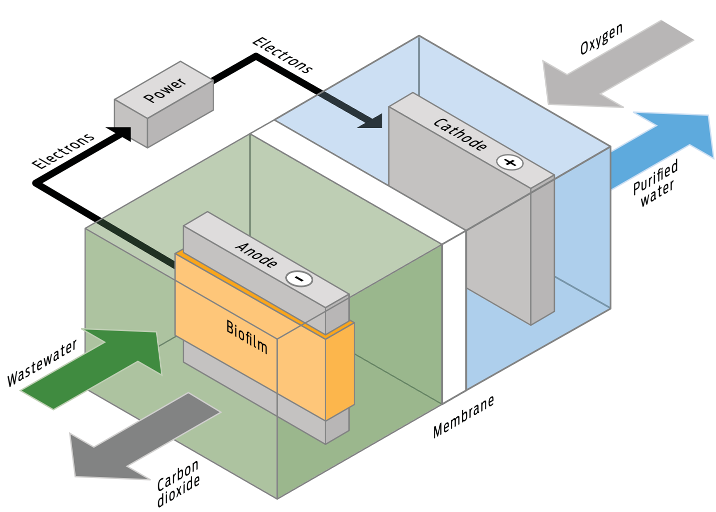


ENERGY TRADE-OFF

Coupled with a desalination plant, osmotic power could generate 3 watts of electricity per square meter of membrane, partly recouping some of the energy cost of desalination.

WHAT'S NEXT

Statkraft's 10-kW-capacity pilot plant began operating in November 2009 in Tofte, near Oslo. The company says it can have a full-scale plant operating by 2015.



BUG POWER: MICROBIAL FUEL CELLS

HOW IT WORKS

Microbial fuel cells can generate power by cleaning contaminated salty water. The bacteria eat salt and other substances in the contaminated water, and as they clean the water, they generate excess electrons as part of their metabolic processes.

UPSIDE

Self-cleaning; generates power for desalination.

DOWNSIDE

Still in the lab.

BEST FOR

As yet, this technology is being studied only for wastewater and brackish groundwater.

ENERGY TRADE-OFF

Will generate rather than consume energy—if it works.

WHAT'S NEXT

Research on microbial fuel cells is ramping up around the world, including at the University of Queensland, in Brisbane, Australia, and Tsinghua University, in Beijing. Engineers at Oak Ridge National Laboratory, in Tennessee, are working on combining these fuel cells with a capacitive-deionization reactor.

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VALLETTA, THE CAPITAL OF MALTA

MALTA TAKES CONTROL

With the world's first multiutility smart grid, Malta aims to save water and money

BY HARRY GOLDSTEIN

"IN THE MEDITERRANEAN, NOBODY wants to pay for anything!" my cab driver bellows as he drops us off at the headquarters of a Maltese utility. He's railing against electricity theft. It's a problem that many people here would prefer not to discuss. Our cabbie isn't one of them. He doesn't know it, but with me in the car is Roberto Aguilera Gonzale, IBM Global Services' program manager for a project to install technology that should put an end to the theft—and do much more.

Here in this tiny nation of 400 000, a seven-island archipelago strung between Italy and Tunisia, IBM is building the world's first smart grid that will govern both electricity and water. For the electricity utility, Enemalta Corp., in Marsa, the €70 million (about US $88 million) grid will make detecting theft easy, distribution fair, and administration efficient. It will also make environmental measures easier to promote, through pricing options that reward conservation and solar energy; solar panels are a viable alternative on these sunstruck islands. Water Services Corp., in Luqa, will use the smart grid to shave kilowatt-hours off its energy bill by optimizing its control systems. And both the electric and water utilities will monitor every watt and liter flowing onto their respective grids and compare those measurements to the readouts of every meter in the system. That way, losses through theft, leakage, and defective meters can be pinpointed quickly.

But while the grid will help both utilities keep a lid on costs, energy and water prices are ultimately tied to Malta's total dependence on oil, its shortage of freshwater, and the fact that as a member of the European Union, it must implement a sustainable water policy this year. Part of that policy is to force water conservation on consumers through price increases. So the government is setting the price of electricity. That in turn determines the price of water, because Water Services uses electricity to extract groundwater and to desalinate seawater, the parched islands' two main sources.

When utility rates rise, of course, everybody blames the government. The inevitable pointing fingers curled into raised fists at the end of February as thousands of trade unionists and ordi-

8600 BY LAND, 3 BY SEA

Malta has the highest density of private wells in the world—30 per square kilometer—for a total of about 8600. These boreholes tap the shrinking aquifers that supply the country with 60 percent of its potable water. The rest comes from three seawater reverse-osmosis plants, located at Pembroke, Ghar Lapsi, and Cirkewwa.

PHOTO: HANS PETER MERTEN/GETTY IMAGES; MAP: ANDREW ZBIHLYJ

MATTHEW MIRABELLI

nary Maltese jammed the streets of the capital, Valletta, to protest hikes in their utility bills. On 1 March, a motion in the Maltese House of Representatives to repeal the new tariffs went down to defeat by a single vote.

Malta's political and geographical circumstances make it a uniquely challenging place to institute new water and energy policies. Unlike Singapore or China, where word from the top decides all matters, the Maltese have a vibrant democracy, one where issues are debated in public and decided on election day, often by razor-thin margins. Unlike the United States or Australia, every decision taken by the national government is local. Each citizen bears the consequences not just of some faceless bureaucrat's whims but also the actions of his or her neighbors. With the country's energy supply at the mercy of world oil markets and its groundwater running out, Malta is approaching the point where the people must choose between conserving water and electricity or paying ever higher prices to desalinate their water and power their homes.

That's where the smart grid will help. With the vast amounts of data it generates, government officials, the utilities, and citizens will be able to make more informed decisions. "You will have thousands of times more information than you have now," says Paul Micallef, who oversees the introduction of the meter management system for IBM Global Services. "Unless you're in the position of the utilities, you can't even fathom the change that's going to happen."

IN MALTA, WATER AND ELECTRICITY ARE inextricably bound—and not just in the minds of protesters and politicians. Roughly one-third of Malta's water comes from three aging plants that squeeze the salt out of seawater through reverse osmosis (RO). Another third is pumped out of Malta's shrinking aquifers by approximately 8600 private borehole owners who extract water free of charge. About a quarter is pumped out of Water Services' own boreholes. The rest comes either from small RO plants run by a few large hotels or from private cisterns that store the scant 550 millimeters of annual rainfall. The cisterns were mandated for all homes by the Renaissance rulers of the islands, the Knights of St. John of Malta, in the 16th century and came in handy during siege or drought.

Electricity accounts for 75 percent of the cost of the water produced by Water Services' RO plants. So when Enemalta raised electricity rates for large commercial customers by 60 percent, it effectively bumped up domestic and commercial rates for water, too, by as much as 25 percent.

Over the years, Water Services has installed a series of technologies to get ever more water from each watt consumed in its RO plants. As a result, the energy used to desalinate 1 million liters of water has dropped from 5 kilowatt-hours 25 years ago to 2.8 kWh today.

The newest plant, commissioned in 1992 at Pembroke, about a kilometer from the upscale hotel district of St. Julian's, has a capacity of 54 megaliters of water per day. As we tour the facility, Pembroke's operations manager, Warren Vella, tells me that in the relatively rainy winter season, the plant operates at less

PROTESTERS ANGRY ABOUT RISING UTILITY RATES FILL THE STREETS OF MALTA'S CAPITAL, VALLETTA, IN FEBRUARY. AT THE PEMBROKE RO PLANT [*TOP RIGHT*], WATER SUCKED FROM THE SEA IS BLASTED THROUGH THOUSANDS OF METERS OF FILTER-FILLED PIPES.

JOSHUA ROMERO (3)

than half that and at 37 ML per day in the summer.

The plant sits on the beach next to a Maltese army shooting range. Seawater is pumped into a reservoir under the plant from boreholes that have been drilled along the seashore. The sediment in the boreholes filters out dead fish, seaweed, and garbage; sand, pebbles, and seashell fragments settle in the reservoir.

The seawater is then shoved at 7 megapascals—enough pressure to shoot a stream of water 700 meters in the air—through a series of pipes stuffed with hollow-fiber or spiral-bound membranes. About 40 percent of the seawater is converted into potable water this way. The remaining brine flows along one side of the plant to drive a Pelton wheel, a turbine that turns a 6-kilovolt motor, which in turn forces fresh seawater through the membranes. Brine flowing on the opposite side of the plant funnels into a mechanical pressure exchanger where it spins a ceramic rotor, which imparts that pressure to new seawater entering the exchanger from the other side. Finally, the brine leaves the system and returns to the sea.

At each stage in the conversion of saltwater to fresh you can hope to save energy only if you can control pressure and flow rates precisely. That's the point of linking the smart grid to the utility's existing supervisory control and data-acquisition system. With historical and real-time data at their fingertips, Vella and his colleagues expect to take advantage of such conditions as lower seawater salinity, when less pressure is needed to push the water through the membranes.

Until recently, most of Water Services' engineering efforts have been aimed at saving energy and stopping leaks. Now the utility is turning its attention to detecting and plugging a different kind of leak: commercial losses that stem from meters that aren't sensitive enough to measure very low water flow.

Over the next three years IBM will outfit the old water meters with new data-collection modules. The modules convert the analog pulses to digital signals, which are then radioed to devices called concentrators that collect data from meters located in a particular zone and transmit that data in batches to Water Services. By comparing the amount of water being read by individual meters with the amount of water flowing into each zone, the utility will discover discrepancies that will help them track down slow leaks.

"It's a powerful tool to basically drill down and go to the key problem areas," says Stephen Galea St. John, Water Services' chief officer of operations. "It's a question of low-lying fruit."

IT'LL TAKE A FEW YEARS TO PLUCK that fruit. The five-year project began in 2009 and involves more than 100 IBM personnel working alongside about twice as many employees from the utilities.

Dozens of programmers, engineers, and project managers click away on ThinkPads in a situation room at Water Services' headquarters. Here they're knitting together the business systems that will ingest, analyze, and act upon the hundreds of thousands of data points that the water and electric meters will generate each day. In some instances, programmers are building things from scratch, such as an advanced meter management system, which both Water Services and Enemalta will use. IBM is also replacing the billing system the two utilities have long shared with a new one from the German firm SAP. Actual consumption and billing data will be available to customers via a new Web portal that accepts online payments and helps customers understand their own consumption patterns.

Just as Water Services' newly outfitted meters will help minimize commercial losses, the electric smart meters made by Enel, of Italy, are the first line of defense against electricity theft. Four years ago government officials estimated that Enemalta was losing up to 14 percent of its electricity to theft. More recent estimates show total commercial losses of 8 percent, with theft being a major factor.

JOSEPH GIULIANO, AN ENEMALTA TECHNICIAN, INSTALLS A PLATE THAT HIDES THE WIRES CONNECTING TO NEW SMART METERS [*top*]. NEXT, HE PROGRAMS THE METERS WITH CUSTOMER INFORMATION [*bottom left*]. AS A FINAL STEP AGAINST TAMPERING, HE SEALS EACH METER WITH A BAR-CODED PLASTIC TAG [*bottom right*].

JOSHUA ROMERO (3)

As Anthony Gauci, project manager for automated metering at Enemalta, explains over the whine of a drill during an installation, electricity thieves are an enterprising lot, and they love the old electromechanical meters. Popular tampering methods include drilling a hole in the meter cover and inserting an object to stop the unit-counting disk from rotating; turning the meter at an angle so that the disk touches the magnet inside the meter and stops rotating; opening the link between the voltage and current coils so the meter registers no consumption; and splicing in a wire to bypass the meter completely and connect the power directly to the main switch of the thief's home or business.

With curious residents looking on, Enemalta technician Joseph Giuliano takes out the building's 10-year-old analog meters and replaces them with the smart meters. He also installs a plate that hides all the cables connecting to the meters, a simple but effective measure to thwart would-be splice-and-bypass thieves.

Giuliano works with a handheld device that plugs into the meter and programs it with customer contract information. Once installed and locked with bar-coded seals, the meters communicate over power lines at 2.5 kilobits per second with a data concentrator inside the local substation. The substation concentrator in turn sends data wirelessly to Enemalta's main offices.

As of February, technicians had installed more than 11 000 smart meters in a handful of test zones. The plan is for 80 000 smart meters to be installed each year for the next three years. By the beginning of 2013, all of Malta's electricity and water meters should be hooked up to the utilities' respective computer networks.

The meters store consumption, profile, and event data and are periodically polled by the central system. By measuring how much electricity is being put on the grid and comparing that with the electricity the smart meters are registering, Enemalta can spot discrepancies

ILLUSTRATION: BRANDON PALACIO

Powered By *Crazy*

ATMOSPHERIC WATER GENERATION

Extracting freshwater from thin air is a seductive idea, especially for arid places that see little rainfall but are also very humid, like parts of Mexico and South America. A number of companies now sell home-scale atmospheric water generators—basically glorified dehumidifiers.

The WaterMill, for example, from Canada's Element Four, can produce up to 11 liters of drinking water a day (what an average family might use on a tight water budget). The appliance uses an ultraviolet lamp to kill bacteria and bugs. Element Four dreams of using its atmospheric generators to supply safe drinking water in poor rural areas. But a planned 20-liter-per-day generator can soak up 720 watt-hours per liter, and such places often have an unstable electricity supply, or none at all. And when you consider where the electricity comes from, the WaterMill makes even less sense. A typical coal-fired power plant consumes about 1.8 liters of water per kilowatt-hour of electricity generated. If that's your power source, it would actually *take* 1.3 liters of water to *make* one liter of water. Really.

Still, the device is headed for testing in Australia, Mexico, South America, and the Bahamas, where the main goal is just to have a consistent source of clean water, no matter the energy cost. *—Anne-Marie Corley* and analyze them with IBM's Cognos software to identify the nature of the losses. System administrators can also query the meters and control the amount of power available to a customer. That's a huge change from today, when meter readings (done at most twice a year), service adjustments, and power cuts to nonpayers must be performed in person.

EVEN IF ENEMALTA WRINGS EVERY LAST cent from its grid, the potential for much higher electricity and water prices looms. Enemalta has no plans to replace its oil-fired power plants, so it will be subject to the vagaries of the petroleum market for the foreseeable future. To further complicate matters, studies show that saltwater is infiltrating Malta's aquifers, which supply about 60 percent of the country's freshwater. That will inevitably lead to a shift toward more seawater desalination and more energy consumption.

Gordon Knox, who spent 28 years as a geologist with Shell Oil Co. and now studies Malta's aquifers, believes the country is headed for a reckoning. Malta has a porous rock system, Knox tells me, with nooks and crannies into which either rainwater or seawater can infiltrate. In the aquifers, freshwater floats on top of the denser seawater. This freshwater layer, known as a lens, is dynamic: When water is pumped out of an aquifer, the freshwater lens becomes thinner, and seawater takes its place beneath. Studies by the Malta Resources Authority and the Malta Environment and Planning Authority predict that in just five years, the groundwater may no longer be usable. Knox's own estimates, which are based on publicly available data, place the date for total groundwater salinization as far out as 2025.

Knox is convinced that if business as usual continues, Malta will be forced to produce all of its water with reverse osmosis. While Water Services' existing RO plants can meet all of Malta's current needs, costs would skyrocket. He figures the desalinated water costs residents about five times as much as groundwater. So shifting entirely to desalinated water—all other factors being equal—would triple consumers' water bills. And if oil prices rise, water prices would rise even more.

Water Services' St. John agrees that groundwater salinization is inevitable if nothing is done to curb usage. So he is preparing for the worst. His team is working with the Malta Resource Authority to research ways to replenish the aquifers. One idea is to run treated wastewater through RO and use additional disinfection measures before pumping it back into the ground.

Meanwhile, the water price increases are encouraging individual Maltese to take matters into their own hands. "Now that the water price has run up, we can see already a lot of actions," says Joseph Cilia, a professor in the power and control engineering department at the University of Malta. Cilia's own home is a showcase of the Maltese home of the future. He recently installed photovoltaic panels with help from government subsidies. He also placed the water tanks of his toilets 3 meters above the bowls and set them up to flush automatically, thereby cutting his water bill by 40 percent.

"It's often human nature that when faced with a real crunch, they're then energized to do something about it," Knox says. If that's true, maybe the Maltese can conserve their way to a sustainable future. The alternative, to paraphrase that cab driver, is one nobody wants to pay for. ❑

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Graduate Assistantships in Embedded Software Engineering/ Electrical Engineering

Gannon University has graduate assistantships available for the Fall 2010, semesters for the two-year Masters Program in Embedded Software Engineering/Electrical Engineering. Prospective candidates must have BS in Electrical/Computer Engineering or equivalent. Traineeships include full tuition and a yearly stipend of $30,000. Successful candidates will work on industrial projects under faculty direction that are integrated with their course work for approximately 20 hours/week during the school year and 50 hours/week during the summer. Candidate must have at least four years of work experience to be eligible for consideration.

Candidates should apply on-line at **http://www.ecs.gannon.edu/GETS.**

Please contact Dr. Fong Mak (mak@gannon.edu) for Embedded Software Engineering/ Electrical Engineering.

THE CHINESE UNIVERSITY OF HONG KONG

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Professor / Associate Professor / Assistant Professor

(Ref. 0910/144(370)/2)

The Department invites applications for a faculty position at Professor / Associate Professor / Assistant Professor level for its new Biomedical Engineering Programme.

The Programme is specially looking for outstanding candidates who have expertise in at least one of the following areas: biomimetics, nano/micro fabrication of devices related to biomedical applications, biotechnology, electrophysiology, neuroscience or biomedical sensors and instrumentation, as well as an excellent track record of research and publications in internationally recognized peer-reviewed journals. Applicants should have (i) a PhD degree in engineering related to the biomedical discipline; (ii) demonstrated excellence in teaching and research; (iii) outstanding academic qualifications and stature; and (iv) the ability to establish independent research projects and provide leadership in their area of research. The appointee will (a) teach undergraduate and postgraduate courses; (b) establish independent and collaborative research projects; and (c) supervise research students. Appointment will normally be made on contract basis for up to three years initially commencing August 2010, which, subject to mutual agreement, may lead to longer-term appointment or substantiation later. Review of applications will begin immediately, and applications will be accepted until the post is filled. For enquiries, please contact Professor K.T. Chan, Director of Biomedical Engineering Programme, Department of Electronic Engineering (e-mail: *ktchan@ee.cuhk.edu.hk* or tel: (852) 2609 8259).

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Salary will be highly competitive, commensurate with qualifications and experience. The University offers a comprehensive fringe benefit package, including medical care, plus a contract-end gratuity for an appointment of two years or longer, and housing benefits for eligible appointee. Further information about the University and the general terms of service for appointments is available at *http://www.cuhk.edu.hk/personnel*. The terms mentioned herein are for reference only and are subject to revision by the University.

Application Procedure

Please send full resume, copies of academic credentials, a publication list and/or abstracts of selected published papers together with names, addresses and fax numbers/e-mail addresses of three referees to whom the applicants' consent has been given for their providing references (unless otherwise specified), to the Personnel Office, The Chinese University of Hong Kong, Shatin, N.T., Hong Kong (Fax: (852) 2696 1462). The Personal Information Collection Statement will be provided upon request. Please quote the reference number and mark 'Application - Confidential' on cover.

The Electrical Engineering and Computer Science Departments of the Universidad de Chile

invite applications for two full-time faculty positions in Advanced Networks and Future Internet Services at the Assistant or Associate Professor level.

The main duties of these positions are undergraduate and graduate teaching, and research at the Universidad de Chile (located in Santiago, Chile). These positions are part of a new interdisciplinary program, which seeks to foster research and teaching in an area shared by the EE/CS departments. Details are available at

http://ingenieria.uchile.cl/concursos_academicos2010

Universität Stuttgart

The University of Stuttgart, Germany, invites applications for a

Full Professorship (W3) for Radio Frequency Technology

in the Department of Computer Science, Electrical Engineering and Information Technology. The appointee will head the institute of the same name.

The professor contributes to undergraduate and graduate teaching in the degree programs of electrical engineering and information technology as well as in the international Master program "Information Technology".

The main research areas at the institute are:

- Components and systems of wireless communication
- Wave propagation models and localization techniques for mobile communications
- Numerical methods for the computation of electromagnetic scattering problems
- Radio navigation systems
- Antennas and field measurement techniques
- Electromagnetic compatibility

The acquisition of research funding is expected.

Applicants are expected to have excellent scientific skills in at least two of the above mentioned topics as well as didactic qualifications. Experience in industrial research is desired.

The requirements for employment listed in § 47 and § 50 Baden-Württemberg university law apply.

Applicants are asked to send their CV and accompanying documents to the Dean (Dekan der Fakultät 5, Universität Stuttgart, Pfaffenwaldring 47, 70550 Stuttgart, Germany or E-Mail: bewerbung-ihf@f-iei.uni-stuttgart.de) before June 20th, 2010.

The University of Stuttgart has established a Dual Career Program to offer assistance to partners of those moving to Stuttgart. For more information please visit the web-page under: www.uni-stuttgart.de/zv/dezernat4/pers-entw/dual-career.html

The University of Stuttgart wishes to increase the proportion of female academic staff and, for this reason, especially welcomes applications from women. Severely challenged persons will be given preference in case of equal qualification.

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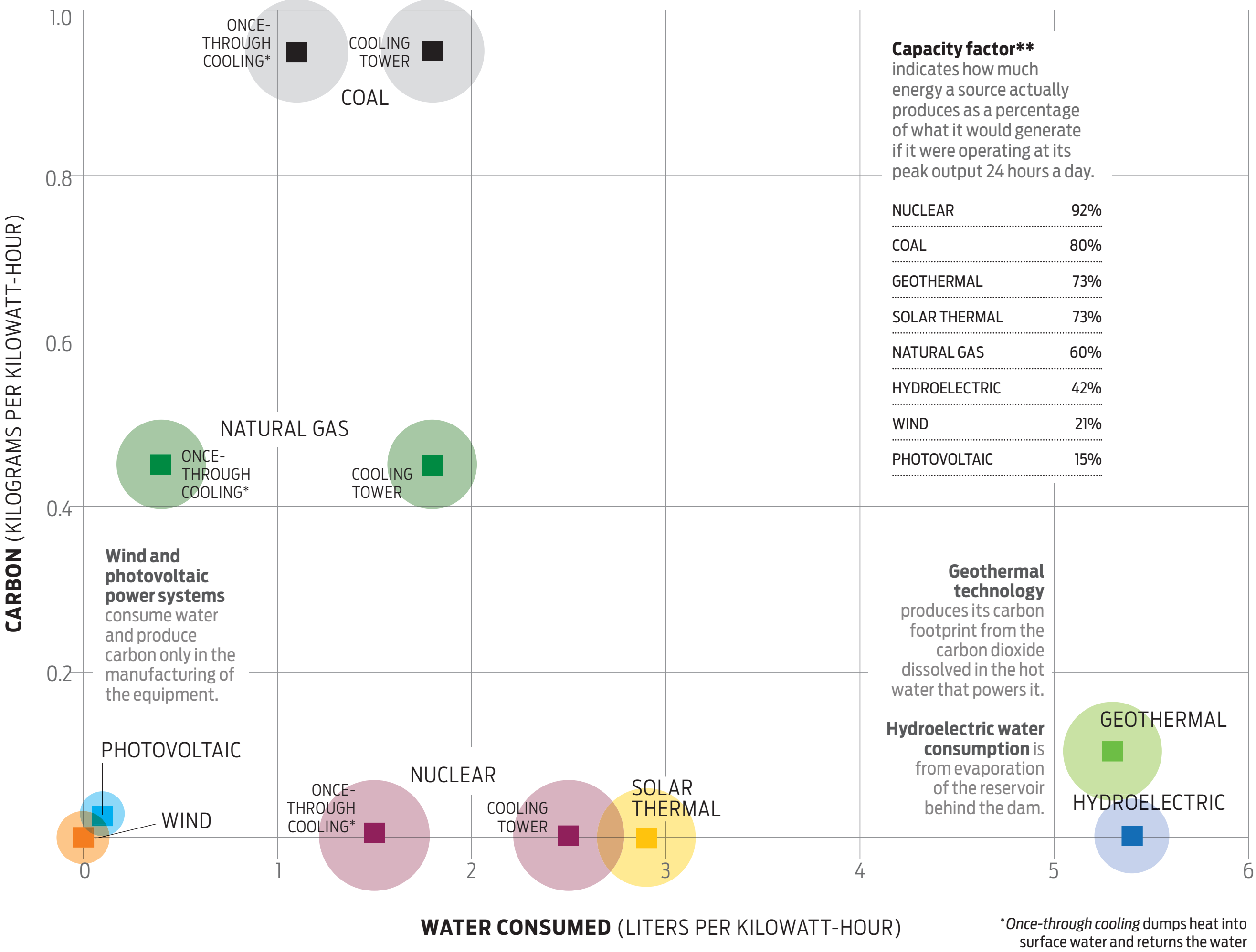


WATER CONSUMED (LITERS PER KILOWATT-HOUR)

* *Once-through cooling* dumps heat into surface water and returns the water to its source. Relatively little water is actually consumed by evaporation, but much more water must be available for the power plant to withdraw.

** Circle size indicates capacity factor.

Carbonated Water

IT'S NOT enough to reduce carbon dioxide emissions from energy production, according to a 2009 report by market research firm Lux Research, in Boston. You have to worry about water too. The company plotted the carbon intensity (in kilograms per kilowatt-hour) and the water intensity (in liters per kilowatt-hour) of typical "green" and "dirty" sources of energy to illustrate how tightly bound carbon and water are. Fortunately, certain technologies could let us break the link.

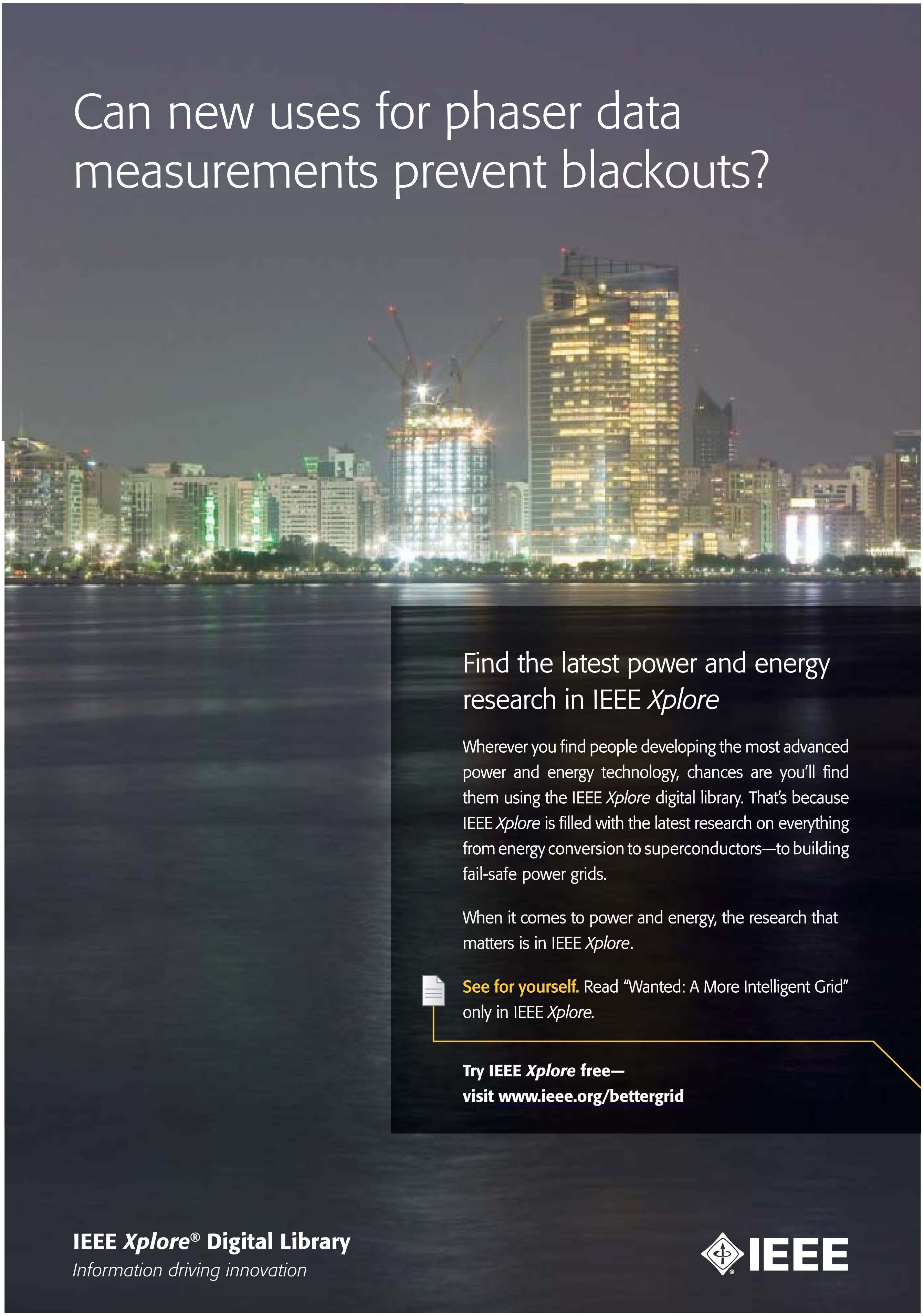
As you might expect, solar photovoltaic and wind power produce the least carbon and consume the least water, even if you take into account the water used in manufacturing the equipment. But they are intermittent sources that can't be depended on 24-7. Nuclear power doesn't have that problem, but it's a much thirstier way to make electricity. In short, there are no perfect solutions.

Improving efficiency can reduce both carbon output and water consumption, and indeed there are technologies available now that can blunt a power plant's water needs, according to the analysis. But Lux senior analyst Michael LoCasio has a more radical suggestion: Restructure the power grid. Loss-limiting, long-distance, high-voltage DC lines could transmit water- and carbon-free solar photovoltaic power from sunny-but-dry deserts. They could also let us build those thirsty nuclear power plants on the coasts, where they would drink only abundant ocean water.

The trouble is that alternate low-water and low-carbon technologies cost money, whereas both water and carbon are, in most places, still quite cheap. Real change to our energy mix will require a recognition of their real costs.

—*Samuel K. Moore*

Source: "Global Energy: Unshackling Carbon From Water," Lux Research, June 2009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