momentum

Institute on the Environment • University of Minnesota • Fall 2011

FOR GREAT LAKES' SAKES

INTERNATIONAL COLLABORATION HELPS EARTH'S LARGEST LAKES THRIVE IN THE FACE OF HUMAN-INDUCED CHANGE

Chemistry we can live with

Q&A: Fresh(water) thoughts with **SANDRA POSTEL**

PLUS... **e-waste in the U.S.** *and* **biofuels in Brazil**

Hitting the Water Wall

AS I TRAVEL AROUND THE COUNTRY, I'm often asked about the looming water crisis. Whether it is the decline of groundwater in northwestern India, last summer's floods in the Upper Midwest, drought in the Horn of Africa, or the fate of the world's great lakes, water seems to be on everyone's mind.

And, in many cases, I've been hearing people say that we're "running out of water."

There is no doubt water issues are mounting. But let's be clear: We're *not* running out of water on the planet as a whole. The amount of water on Earth is the same as it's been for billions of years. And the amount of water flowing across our continents toward the ocean—through groundwater, lakes, streams and rivers—is largely what it's been for all of human history.

What we *are* running out of is the *ability to consume water without limits, without concern about pollution, when and where we want to.* In a nutshell, we're hitting the water wall.

Fueled by growth in population and affluence, we continue to consume water as if there were no limits, even as we see the clear warning signs—depleted aquifers, drying lakes and diminished river flows. Once again, we find that the exponential growth of human consumption has run into fundamental planetary resource limits. You can't continue to consume water faster than your watershed can deliver it, period. Meanwhile, the quality of freshwater supplies is being compromised by pollution from farms, industries and communities, leaving water that is often unhealthy for ecosystems and people. And the behavior of the water cycle appears to be growing increasingly extreme due to climatic changes—with more floods and more droughts—which we will have to become better at adapting to and planning for.

"Water itself is not becoming scarce on the planet. What is becoming scarce is our ability to **USE AS MUCH AS WE WANT**."

Water itself is not becoming scarce on the planet. What is becoming scarce is our ability to use as much as we want, whenever, however, and wherever we want.

And there lies the rub: In most places in the world, there is sufficient water to sustain basic human needs while leaving enough for nature, *if* we manage it well. But good management demands completely new approaches to our water economy that meet our fundamental economic and societal needs, preserve adequate water stocks and flows for natural systems, and are much more resilient to climatic disturbances.

This requires an entirely new way of thinking about water. It requires moving from a mind-set of exploitation (which presumes water resources are essentially infinite relative to our demands, and growth can continue forever) to a mind-set that respects the limits and fragility of our water supply. It requires learning to live within our water means. And it requires becoming more resilient in our interaction with water: hoping for the best, but always planning for the worst.

Fortunately, as we see in this issue of *Momentum*, many pioneering efforts are moving in the right direction. The Large Lakes Observatory at the University of Minnesota Duluth is sharing discoveries across continents to help sustain the enormous benefits the world's biggest freshwater systems afford. Global Water Policy Project founder Sandra Postel is working to align humans' water use with nature's constraints. Kate Brauman, a postdoctoral fellow with the Institute on the Environment's Global Landscapes Initiative, is identifying how water can be strategically allocated on a global scale to support food production without undermining the ecological integrity of aquatic systems. And, with a focus on Minnesota but an eye to global impact, Water Resources Center co-director Deborah Swackhamer has created a comprehensive plan for sustainably managing Minnesota's waters that could become a model for other states and even nations facing the common challenge of reconfiguring our demand to fit supply.


PHOTO BY JOE TRELEVEN

Through these and other efforts, scientists, policy makers and others are emerging with strategies to manage our water resources in new, intelligent ways that ultimately can help us reconcile our growing demands with Earth's abundant, but not boundless, supplies of freshwater.

If we continue to think of clean, abundant water as a given, we will hit the water wall. But if we re-imagine water as what it is—a renewable but finite resource—and apply our infinite imagination to developing and carrying out practices that sustain it, we should have plenty to meet our needs, nature's needs and the needs of future generations as well.

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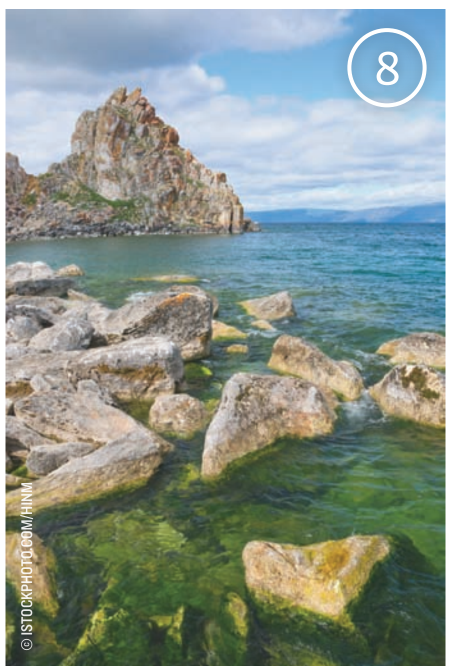
on the cover Workers transfer goods from a *barkasse* to the MV Liemba, a vessel that carries passengers, pineapples, dried fish and other cargo among communities along the shore of Lake Tanganyika in Africa. Shared by Burundi, the Democratic Republic of the Congo, Tanzania and Zambia, the 420-mile-long lake provides not only transport but also food, drinking water and other goods and services to more than a million people—all while supporting one of the world's largest freshwater ecosystems. © *iStockphoto.com/guenterguni*

DEPARTMENTS

FEATURES



Water World

Interview by **TODD REUBOLD** | photo by Van Royko

Whether it's 500-year floods or 100-year droughts, water has been one of the top news stories in 2011. And good ol' H_2O will likely grow in prominence over coming decades as rising demand due to rapid population growth collides with increasing unpredictability of supply. *Momentum* recently caught up with SANDRA POSTEL, founder of the Global Water Policy Project, to discuss how we might help shape a positive future for the world's freshwater resource. »

> "The entire path of development over the 20th century has been about acquiring more water. And that worked for a time, but **CLEARLY IT'S NOT WORKING ANYMORE.**"

CAN YOU TELL ME MORE ABOUT THE ORGANIZATION YOU FOUNDED? The Global Water Policy Project is an umbrella for a variety of things that I do, but the goals really are to begin to move ideas and policies and advance ways of harmonizing human use of water with the protection of the natural world. It's really focused on the question of, "How can we begin to meet the needs of this growing human population while sustaining the ecosystems that support not only the rest of life, but us, too?"

WHEN DID YOU FIRST BECOME INTERESTED IN WATER-RELATED ISSUES?
I've been interested in environmental issues since I was at least a teenager, if not earlier. When I left grad school at Duke I took a job with a small natural resources consulting firm in California and was given the opportunity to work on freshwater issues. We had some work going with the EPA and the Army Corps of Engineers, and so I got my feet wet, so to speak, in water pretty early out of grad school.

HOW WOULD YOU CHARACTERIZE OUR RELATIONSHIP WITH WATER TODAY? We know that freshwater is finite, it's the basis of life and there are no substitutes for it. But there's a big disconnect with these known truths about freshwater and the way we go about using and managing it. The entire path of development over the 20th century has been about acquiring more water. And that worked for a time, but clearly it's not working anymore. The challenge is to reintegrate how we use and manage water with those fundamental truths about freshwater. Once you start aligning our use of water, our policies around water and our management goals around water with those fundamental truths, it shifts everything.

ISSUES LIKE CLIMATE CHANGE AND ENERGY SEEM TO GRAB ALL THE ATTENTION, BUT YOU'VE SAID ONE OF OUR GREATEST CHALLENGES—IF NOT *THE* GREATEST—WILL BE RELATED TO WATER. CAN YOU ELABORATE? We've got different wells in different parts of India that are running out, again from pumping of groundwater. We've got rivers of various sizes all around the world in the drier parts of the world that had been perennial rivers that are now not flowing over extended periods of time from overuse. So, I think it's beginning to hit home in more places, and it's connecting the dots and saying, "We can do something about this. This trajectory does not have to continue in this way."

WHERE DO YOU STAND ON THE USE OF WATER FOR IRRIGATION? I think it's necessary. Irrigation has been a cornerstone of human civilization for at least the last 5,000 years. We get about 40 percent of our food from the 18 percent of cropland that's irrigated. And given the size of our population, I think using that land productively and applying water to it is critical. That said, there are so many ways that the current irrigated agricultural system is not using water efficiently and productively. There's an awful lot that could be gained and a lot of water that could be freed up for other uses if we made our irrigation systems and the entire irrigated agricultural enterprise more efficient and productive when it comes to water.

WHAT'S YOUR OPINION OF THE PRIVATIZATION OF WATER? Water is not just a commodity or an input to our production systems. It's the basis of life, which makes it fundamentally different from just about every other commodity we deal with. So, to me, that means that we really shouldn't privatize water. That said, I think there's absolutely a role for the private sector when it comes to water management.

YOU'VE ALSO COMMENTED ON THE NUMBER OF FRESHWATER SPECIES THAT ARE GOING EXTINCT. IS THIS A GLOBAL PHENOMENON? Global estimates of the projected rate of loss of freshwater species are four to six times those of terrestrial and marine species. If we look at the numbers in the United States, more than two-thirds of freshwater mussels, which do a terrific job of cleansing water, are at some degree of extinction. Close to 40 percent of fish species in North America are at risk of extinction. So these numbers are very concerning and again reflect that we haven't been managing water with the protection of life and the web of life at the core.

IF YOU COULD CHANGE THE WAY WATER WAS MANAGED, WHERE WOULD YOU START? Number one for me would be to say that not only should people have their basic water needs met, but also I think we need to do the same thing for ecosystems. So that means putting ecosystems and the health of ecosystems right at the core of our water decisions and saying, before we allow more to be extracted for this or that use, we need to make sure the ecosystems themselves—the river systems, the wetlands that we rely on—get the water, get the flows that they need. And this is where the game changing comes in. Because once we do that, we've not only secured a healthier environment or a healthier set of ecosystems, but we've basically said, "Okay, given that those flows need to go to the ecosystems, the remaining water is what we have to manage for human uses—for drinking, for industry, for agriculture." So it drives up the productivity of water use. Once we don't go out and look for more water anymore, we become a lot more efficient and productive with the water that we have.

ARE THERE PLACES WHERE WATER POLICIES AND PRACTICES BALANCE BOTH HUMAN AND ECOSYSTEM NEEDS? Certainly we've seen policies adopted that have those principles on paper at their core. South Africa was one of those countries, if not the first country, that adopted a very progressive water law that said not only people but ecosystems should get the quantity, quality and timing of flows that they need to be healthy. We've got, for example, a city like Napa, California, having endured numerous floods, deciding to try something different. They're calling it the "living river approach" to flood control, where they're reconstituting wetlands and giving the river some of its floodplains back. Cedar Rapids, Iowa, is also looking at a different approach to flood control that brings in wetlands and the floodplains again. And we have the New York City example, where they've avoided a $10 billion filtration plant by investing in watershed protection, letting the healthy watershed do more of the work of filtering pollutants out.

WHAT'S THE TAKEAWAY MESSAGE? I guess the final thing is, understanding our own water footprint and how much water flows through our daily lives on an individual basis. It's important that people have a comprehensive sense of the total water that feeds their lives every day. If you're an average American, about 2,000 gallons of water flows through our lives every day. And more than half of that is our diet. And so understanding that the choices we make about what we consume and how much of it to consume and so on can make a big impact, not just in our local watershed but in other watersheds around the world where those products are grown and made. The simple choices we make every day can have a beneficial impact on other places around the world if enough of us make more conscious choices about what to consume. **Q&A**

FOR THE FULL INTERVIEW:
environment.umn.edu/momentum/webex

People and the Forest

Photos and text by JASON HOUSTON

Guinness World Records declared in 2008 that Indonesia had the world's fastest deforestation rate. Borneo alone has lost more than 50 percent of its original forest cover; half of that loss occurred in the past 20 years due to logging, mining, fire, development of palm oil plantations and other habitat-destroying human activities.

Stopping deforestation throughout the tropics has become one of the global conservation movement's top priorities. Deforestation's repercussions go far beyond the loss of endemic wildlife and the displacement and impoverishment of local people. Vanishing species leave holes in the web of life that ultimately sustains all humans. And deforestation arguably causes more damage to the climate than any other human activity.

But deforestation is not a simple problem, and there is no simple solution. In Borneo, questions about whether to conserve forests, burn them for farmland, or log them and plant the land with oil palms are tied up in complex cultural and economic considerations. While conservation has long been science driven, success will ultimately come down to changing the way people relate to nature.

These images depict some of the social complexities of conservation along the border of the newly established Lamandau River Wildlife Reserve in Indonesian Borneo.

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2

3

(1) Malay rubber tappers' outpost on the Rasak River (2) oil palm kernels (3) native seedlings being grown for reforestation (4) resident orangutan and baby (5) Togu Simorangkir, director of Yayorin, a local non-governmental organization focused on orangutan conservation through education and environmentally sustainable development alternatives (6) an old-growth stump next to a new palm oil tree (7) Luparia tapping rubber in Tempayung (8) afternoon rains in burned forest areas leach nutrients from the soil, leaving only sand.

VIEW A SLIDE SHOW PORTRAIT OF THE PEOPLE OF LAMANDAU RIVER:
environment.umn.edu/momentum/webex

Happening at IonE

Acara Summer Institute

Which of these bright ideas can best help overcome food and water challenges in developing countries? A. Fight hunger and thirst with text messages. B. Beat disease with pay toilets. C. Improve food quality in school lunches. D. Boost crop yields with mini greenhouses. The correct answer for the IonE-funded Acara program

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was "E. All of the above" as four international student teams participating in its Acara Challenge competition were chosen to move their winning sustainable development business ideas toward commercialization at the Acara Summer Institute in Bangalore, India. Learn more at **environment.umn.edu/acara**.

All About Algae

They're alive, they're green, they pack power—and they'll be the talk of the town Oct. 24–27 when hundreds of algae growers, equipment manufacturers, investors and more gather in Minneapolis for the fifth annual Algae Biomass Summit. An anticipated 600+ participants will share insights and forge new connections aimed at tapping algae as a fuel source. Learn more at **z.umn.edu/algae**.

Geothermal Takes a Twist

We can store CO_2 underground. We can draw heat up to turn turbines. Why not do both at the same time? With funding from IonE's Initiative for Renewable Energy and the Environment, Martin Saar and Jimmy Randolph (CSE) showed it could be done. Now they're planning to form a start-up around their innovative approach to producing renewable energy while reducing greenhouse gases. "This is probably viable in areas you couldn't even think about doing regular geothermal for electricity production. In areas where you could, it's perhaps twice as efficient," Randolph said.

Lead the Way

This just in from the Greek God of the North Wind's Minnesota branch office: professional development opportunities for emerging environmental movers and shakers. IonE's new Boreas Leadership Program will help U of M grad students, professional students and postdocs sharpen their skills in three key areas: communications and media; cross-sector, integrative leadership; and systems dynamics.

Changing Arctic

Now you see it, now you don't: Fun for magic shows—for ecosystems, not so much. The Changing Arctic: International Cooperation and Development half-day symposium Oct. 27 in Minneapolis will explore present and future challenges and opportunities facing one of Earth's most vulnerable places. Learn more at **z.umn.edu/changingarctic**.

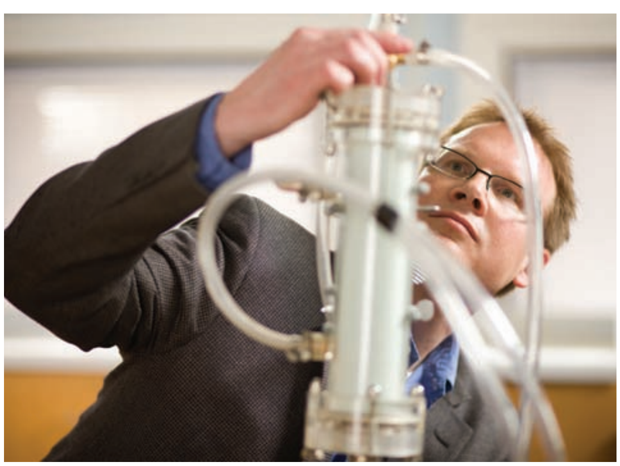

PHOTO BY JOSH KOHANEK

PHOTO BY JOSH KOHANEK

WORTH WATCHING

Wish you could talk to environmental superstars MAJORA CARTER, HANS ROSLING and SYLVIA EARLE? Next best: let them talk to you! Excerpts and full-length video for the trio's Momentum 2011 presentations are now online. Enjoy the show, then share with a friend: environment.umn.edu/momentum/eventseries. Watch for information on the Momentum 2012 lineup soon.

Ongoing Momentum

Like what you see in *Momentum* and wish you could see it more than three times a year? You can! New articles appear regularly on *Momentum*'s website. To sign up to be e-notified when they do, go to **environment.umn.edu/connect**. You can also keep current through our social networks: **facebook.com/MomentumIonE** and **twitter.com/MomentumIonE**.

Kudos

Congratulations to IonE resident fellow Tom Johnson (SCSE), named a fellow of the American Geophysical Union ... to Michelle Linhoff, new associate director of IonE's NorthStar Initiative for Sustainable Enterprise ... to John Sheehan, new science director for IonE's Initiative for Renewable Energy and the Environment ... to IonE resident fellow Peter Reich (CFANS), named to the American Academy of Arts and Sciences.

Big Boost for Innovation

Renewable jet fuel, more affordable solar and improved household energy conservation are among the renewable energy innovations getting a boost from IonE's Initiative for Renewable Energy and the Environment's most recent round of funding. All together, 20 projects will receive $4.1 million in large grant, early career grant and seed grant funding. See **environment.umn.edu/iree** for details.

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NorthStar Opportunity

IonE's NorthStar Initiative for Sustainable Enterprise helps industries, governments and individuals move beyond marginal greening to systemic change through collaborative research. NorthStar is now welcoming new participants to help define research initiatives and benefit from their results. For information, visit **environment.umn.edu/northstar**. Current initiatives focus on building tools purchasers can use to obtain comparative information about "green" product attributes and on developing global insights into how companies integrate sustainability into their core business functions.

Box Office

IonE's "Water for Mulobere" video has scored multiple honors for videographer and producer Beth M. Anderson. The documentary on an Engineers Without Borders water project in Africa was named Best in Show in EWB's annual film contest, and was selected for screening at the Awareness, Big Water and Landlocked film festivals. Watch online at **environment.umn.edu/multimedia**.

FRESHWATER WONDER

Trickling from springs, flowing through canyons, filling broad lake basins, freshwater is the lifeblood of our planet. *Momentum* photo contest winner **LANA GRAMLICH** found special delight in the Colorado River as it carves a tight curve around Horseshoe Bend near Page, Ariz. To view a slide show with more inspirational entries, go to **environment.umn.edu/momentum/webex.**

"I was floored by the magnitude and beauty. There's nothing like standing on the edge of that 1,000-foot drop, looking out across the red canyon and the blue, sparkling waters of the Colorado River! Having no wide-angle lens, I took multiple shots of different sections of the landscape and hoped for the best. On my return home I was delighted to find three shots that I could stitch together sufficiently to create this single image."

Case for Excellence

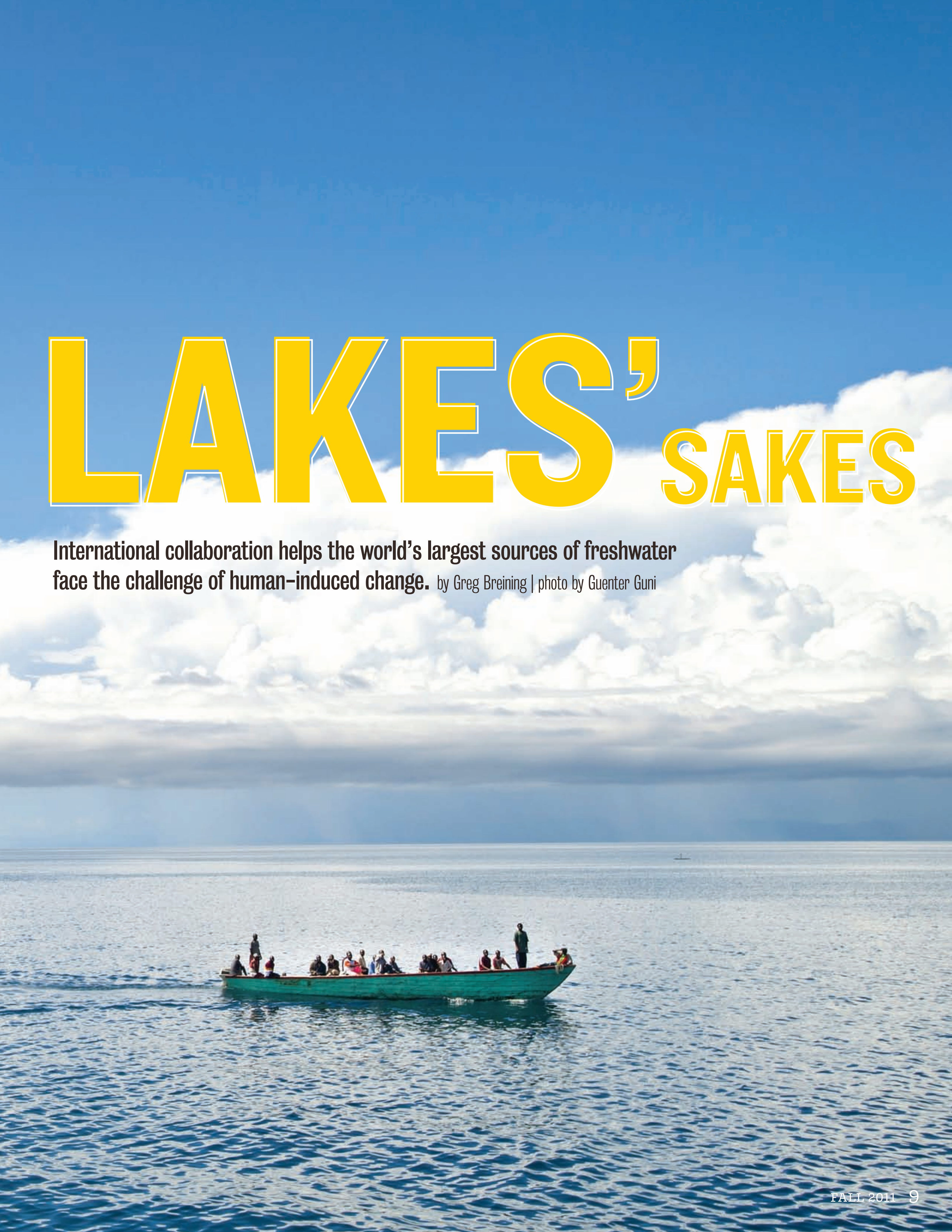
Momentum magazine was one of two gold award winners among 36 entries in the 2011 special interest magazines competition of the Council for Advancement and Support of Education. The award recognizes "superior accomplishments that have lasting impact, demonstrate the highest level of professionalism and deliver exceptional results." The magazine also won an Excellence Award from the University and College Designers Association.

COLLEGE KEY: CFANS, College of Food, Agricultural and Natural Resource Sciences; CSE, College of Science and Engineering; SCSE, University of Minnesota Duluth Swenson College of Science and Engineering

FOR GREAT

LAKES' SAKES

International collaboration helps the world's largest sources of freshwater face the challenge of human-induced change. by Greg Breining | photo by Guenter Guni



The first time aloft over the Canadian North offers an unforgettable sight: Thousands of lakes filling the raw scars of recent glaciers, shimmering in the slanting subarctic light. It's an astounding abundance of water.

Yet if you were to add these hundreds of thousands of lakes to hundreds of thousands of other lakes in northern Europe and Asia, and combine them with the millions of miles of streams and rivers in the world (even the Amazon and Nile and Mississippi), and all the glacial meltwaters and every wetland—if you were to add up all that liquid freshwater, it would only be half the amount contained in the world's 10 largest lakes.

These great lakes—Baikal in Asia; Superior, Michigan, Huron, Ontario, Great Bear and Great Slave in North America; and Tanganyika, Malawi and Victoria in Africa—contain the vast volume of the freshwater on Earth. And they provide for the needs of millions of people.

"Large lakes of the world are magnets for human population. We're drawn to the lakes for easy access to freshwater, we're drawn to them for their aesthetic beauty, we're drawn to them for their fish, we are drawn to them for their transportation services," says Tom Johnson, founder of the Large Lakes Observatory at the University of Minnesota Duluth.

Big as they are, these lakes are not immune to harm. Many have already suffered overfishing, the introduction of exotic species, industrial pollution, and algae blooms and other signs of nutrient inflow from deforestation, agriculture and sewage disposal. And, of course, climate change. All these influences stand to impair the gifts these large lakes provide.

Fortunately, as human pressures increase, our understanding of large lakes is increasing as well. And lessons learned on one continent can help solve problems on another. Researchers studying large lakes around the world share insights pertinent to management, whether it is mitigating the damage of invasive species in U.S. Great Lakes, protecting a rare freshwater seal from industrial contamination of Lake Baikal, or balancing concerns of biodiversity with the needs of African fishermen.

What's So Special?

The world's largest lakes work much like its smallest. The same laws of physics, the same rules of chemistry apply. Sunlight penetrates surface waters, stimulating the growth of rooted plants and free-floating plankton. These are eaten by zooplankton and other tiny herbivores, which are eaten by larger invertebrates and fish. Lakes are warmed by sun, cooled by evaporation. Wind and waves mix their waters and impart currents. Inputs of nutrients increase productivity and turbidity.

From a great lake to a small pond, the processes are remarkably similar, says Sally MacIntyre, a physical limnologist and oceanographer at the University of California, Santa Barbara. "You can use those little lakes as laboratories to understand the big ones."

As size increases, however, so does time. "Residence time"—the time it takes for inflow and outflow to theoretically replace all water in a basin—can run to four centuries in a huge, deep lake such as Baikal or Tanganyika. An oil spill in Baikal, with no known oil-eating microbes, would linger for decades.

Yet scientists are sometimes surprised.

"We used to think that in large lakes changes happen more slowly because they were such large systems. We're finding that that is not always the case," says Norine Dobiesz, research associate with the LLO. The proliferation of nonnative filter-feeding zebra and quagga mussels in Lake Huron has apparently undermined the food chain, causing a swift crash of exotic alewives and Chinook salmon. "So it's making people rethink how fast these large lakes can react," says Dobiesz.

The world's great lakes have large size in common. But they also have important differences.

The world's deepest lakes have formed in geologic faults, or "rifts." These include Lake

The Lake Baikal seal, *Pusa sibirica,* is the only exclusively freshwater seal. Some 80,000 to 100,000 seals are thought to live on or near the big lake. They are found nowhere else in the world.
PHOTOS BY SERGEY GABDURAKHMANOV

Nearly three football fields long, the Lee A. Tregurtha is one of more than 100 lake freighters, or "lakers," that carry iron ore, grain and other goods among the ports lining the North American Great Lakes. A laker can carry a ton of cargo 600 miles on a single gallon of fuel. PHOTO BY P. GORDON

Baikal in Siberia, more than a mile deep with a fifth of the world's freshwater (twice Superior's volume and four times its depth). Lake Tanganyika, largest of the so-called rift valley lakes in East Africa, is nearly as voluminous. Moreover, these lakes are old—30 million years for Baikal, 20 million for Tanganyika. With a long history of evolution, they're home to species found nowhere else. Baikal has 2,500 endemic species. Of its 29 species of sculpins, a deepwater fish, 27 are endemic. Baikal even has a unique freshwater seal.

Large North American lakes, scoured out by glaciers, are comparatively shallow (though Great Slave, the deepest of the lot, reaches to more than 2,000 feet). They are also young, dating to the retreat of the big ice scarcely 10,000 years ago. Most are connected by rivers to nearby lakes. As a result, their species, from diatoms to predatory fish such as lake trout, are widespread.

Big differences also exist between northern and tropical lakes. In temperate climes, cooling water sinks toward the bottom as it reaches its greatest density just above freezing temperature, bringing oxygen to the depths and forcing nutrients to the shallows. Tropical lakes stratify—warm water on top and cool dense water below. Wind mixes the layers but never to great depths. As a result, deep water in these lakes is devoid of oxygen and most life.

Valued by Millions

The world's great lakes provide valuable services to the millions who live nearby. Companies locate on the shores of the North American Great Lakes for a supply of clean water. The lakes have important fisheries (though recreational fishing has far surpassed commercial fishing). They provide low-cost transportation of taconite and grain. They influence the region's climate, boosting snowfall to the ski hills of Michigan's Upper Peninsula and moderating the climate of the cherry- and grape-growing Michigan Mitten.

"One of the things about the Great Lakes is that they are used for so many different industries," says Lynn Vaccaro, coastal research specialist for Michigan Sea Grant in Ann Arbor. In fact, Vaccaro has calculated that more than 1.5 million jobs are directly connected to the North American Great Lakes, generating $62 billion annually in wages. "The Great Lakes are used for so much more than just tourism and fisheries," she says.

But if the North American Great Lakes are valuable, Africa's great lakes are imperative to survival. The number of people who live near the African lakes and depend on them for food and employment is staggering.

But if the North American Great Lakes are valuable, Africa's great lakes are imperative to survival. The number of people who live near the African lakes and depend on them for food and employment is staggering. According to the United Nations, more than 30 million live in the Lake Victoria watershed, 10 million near Lake Tanganyika, and more than 10 million in the Lake Malawi catchment. These numbers are growing 2 to 3 percent per year.

And these lakes mean everything to those who live near them. As one example, lakes Malawi (a deep rift lake with more than 1,000 fish species), Chilwa, Chiuta and Malombe provide food, irrigation, recreation and transportation to more than 13 million in Malawi, Tanzania and Mozambique, according to Daniel Jamu, senior scientist at the WorldFish Center in Zomba, Malawi. Fisheries employ 60,000, and an additional 450,000 work in fish processing, distribution and associated trades. Fish from these lakes supply Malawians 40 percent of their total protein.

"Fish is a critical ingredient for nutritional security in Malawi, where human diets are dominated by maize and cassava," Jamu says.

Feeling the Strain

Big as they are, the world's large lakes are not invulnerable. Dobiesz and colleagues identified 25 metrics—predator-prey balance, food-chain length, number of exotic species, phytoplankton abundance, pollutants and others—to establish trends and gauge the health of ecosystems for Baikal, the African rift lakes and the North American Great Lakes.

The healthiest of the big lakes Dobiesz measured were Tanganyika, Baikal and Superior—not coincidentally the lakes with smaller human populations. Lakes Malawi, Huron and Erie were in a middle, "transitional" group. At the "disturbed" end of the spectrum were Ontario, Victoria and Michigan.

© ISTOCKPHOTO.COM/GRAUY

KILLER LAKE

by GREG BREINING

THE LAST THING YOU WOULD EXPECT OF A BODY OF WATER is that it would explode. Yet one of Africa's largest lakes threatens to erupt, with dire consequences for 2 million people who live around it.

The lake is Kivu, on the border of Rwanda and the Democratic Republic of Congo. Volcanic vents on the lake floor cause the build up of terrific concentrations of carbon dioxide. With the right trigger—a volcanic eruption, an earthquake or simply the ongoing production of gas—the CO_2 might explode out of the water, like the fizz gushing from a giant can of Coke. The invisible, heavier-than-air gas would settle on the shores and asphyxiate residents of lakeshore villages, towns and cities.

Lakes have exploded with fatal results before. In 1984 Lake Monoun in Cameroon released its buildup of CO_2, asphyxiating 37 nearby residents. Two years later, Lake Nyos in Cameroon erupted, killing more than 1,700 up to 15 miles away.

Kivu is more than 1,000 times larger than Nyos, with far more people living in its basin. "Because of its size, it is absolutely unique in the world," says Robert Hecky, professor at the University of Minnesota Duluth's Large Lakes Observatory and head of the Institute on the Environment–funded Global Great Lakes project. Kivu is unique for another reason: It is the only lake known to harbor large concentrations of not only CO_2 but also methane.

Here's how it works. Kivu straddles a volcanic rift. Water seeping through the volcanic sediments dissolves CO_2 as well as various salts. Even though this water is warm, the dissolved materials increase its density enough that it settles on the bottom, up to 1,600 feet deep. "It's a very tenuous kind of stratification," says Hecky. "You have a delicate balance in the deep water." Bacteria decompose organic muck in the sediment, consume CO_2 and produce methane, which also dissolves in the water. As long as the lake remains stratified, the tremendous pressure of the water above keeps the gases in solution.

Scientists hypothesize that the heat of a volcanic eruption or sudden uplift of an earthquake will force gas-saturated water upward. With the drop in pressure as the water rises to the surface, the gas will boil free. Once a bubble-plume begins, it will strip other gas out of solution.

If a large portion of the gas erupts, the lake will bulge at the surface from the violent upheaval. Tsunami-like waves will crash the shore and rebound across the lake. Released CO_2 will settle on the shores and suffocate those who can't escape.

Hecky first studied Kivu in the 1970s. He noticed that in at least five intervals in the past 5,000 years, lake-bottom sediments were missing common microfossils. The absence puzzled him until the explosion of the Cameroon lakes, when he wondered if similar explosions in Kivu had temporarily destroyed or prevented deposition of the plankton. He's now looking for further clues as to whether Kivu underwent past eruptions.

Meanwhile, energy developers are hoping to harvest dissolved methane to reduce danger and provide power. In a technique already being used to provide gas for a small brewery boiler, engineers are designing a platform and pipes to bring deep water to the surface and capture the CO_2 and methane. An existing plant has plans to expand. And Rwanda and the Democratic Republic of Congo are trying to arrange construction of a methane-powered plant of up to 200 megawatts.

"There's a huge demand for electricity," says Hecky. "If you could do this in a secure engineering fashion, it would relieve the gas pressures and make them even less likely to build up over time—though you'd never eliminate that possibility."

The force driving disturbance? "People," sighs Dobiesz, "everything we do. What we really found is it all starts with people. The metrics that changed the most and led to problems with other things were related to how big was the population around the lake."

Dobiesz found the lakes had many problems in common. Overfishing drove down the average size of exploited species. Increasing nitrogen from fertilizer and other runoff fed harmful algae blooms. Shoreline development consumed fish nurseries and wildlife habitat.

In some lakes, industrial pollutants such as PCBs discharged in the water or deposited atmospherically accumulated up the food chain, reaching worrisome concentrations in top predators such as lake trout in North America or seals in Lake Baikal.

Some problems are unique to certain systems. Baikal and the African lakes have few problems with accidentally introduced species because they are not very connected to other lakes (if at all) and don't support shipping from other lakes and foreign seas. But invading nonnative species have colonized North American Great Lakes, with sometimes disastrous effects. Sea lampreys entered through the Welland Canal in the early 1900s and decimated lake trout populations within years. Zebra and quagga mussels hitchhiked aboard the ballast tanks of ocean-going vessels. The filter feeders have helped clean up the waters, but have also disrupted food webs, leading to skinny, poorly conditioned whitefish, a valuable native species.

Dobiesz says her research has helped develop profiles of lake health based on commonly available metrics. These profiles will guide management and research and provide a good picture of changes in lake ecosystems over time.

Heat Wave

Arkady Kalikhman, a scientist who has kayaked Lake Baikal, says that for centuries the big lake has been an icon of "beauty, purity, grandeur and inaccessibility" to those who live around it.

"To my knowledge there's no other natural resource in any other country for which an anthem has been written and all people in that country know or recognize that song," says Marianne Moore, aquatic ecologist at Wellesley College and authority on Baikal. "The lake is a powerful symbol for Russians. It represents for them the unspoiled beauty of the Russian motherland—pristine wilderness."

> A warming climate is expected to increase melting of permafrost in the watershed, releasing nutrients and increasing eutrophication.

The sense of untrammeled nature, however, is belied by data emerging today from a remarkable trove of painstaking field observations gathered by three generations of a Russian family.

Limnologist Mikhail Kozhov directed the Baikal Biological Station at Irkutsk State University when he began sampling water in 1946. Taking a boat in summer and trudging over the ice in winter, he recorded water temperature and clarity and gathered samples from as deep as 2,600 feet. He laboriously identified hundreds of plankton species. Eventually, he was joined by his daughter, Olga Kozhova, and later by granddaughter Lyubov Izmestyeva.

The family's records became known to non-Russian scientists only recently. "It's extraordinary," says Moore. "They sampled so frequently, every 10 to 14 days through all seasons of the year since 1946."

The Kozhov data show Baikal has warmed, especially in summer. Ice covers the lake fewer days than in years past. And that does not bode well for the big lake. Earlier melting might threaten both endemic diatoms that proliferate under the early spring ice and the freshwater seal, which gives birth and shelters pups in ice caves on the lake. A warming climate is expected to increase melting of permafrost in the watershed, releasing nutrients and increasing eutrophication.

Higher temperatures will cause different problems in Africa's great lakes. Warmer surface temperatures will intensify stratification. As a result, the oxygenated surface waters will become shallower; the anoxic depths, even deeper. The zone suitable for crucial fisheries will shrink.

It's fair to say concern over the world's great lakes won't drive solutions to climate change. But concern over a changing climate makes other stewardship all the more important. "Climate change is likely to exacerbate some of the other environmental stressors facing that lake," says Moore. So managers should try to minimize the others, such as reducing industrial pollution or eutrophication.

Razor Thin

Among the challenges that could magnify the threat posed to great lakes threatened by climate change is the growing—and sometimes conflicting—demand for the finite ecosystem services they provide.

Lakes maintain levels by a balance of inflow, evaporation and outflow. In Lake Malawi, the difference is razor thin: 85 percent of the inflow evaporates, leaving 15 percent to exit as the Shire River, tributary to the Zambezi. A little more evaporation, a little less rain, and the outflow ceases, says Johnson. Under such circumstances, he says, "the alkalinity of the lake goes up, the ecosystem changes dramatically because of that

THE GREATEST OF THE GREAT
by volume

1) Baikal (Russia) 23,600 km^3

2) Tanganyika (Tanzania, Congo, Zambia & Burundi) 19,000 km^3

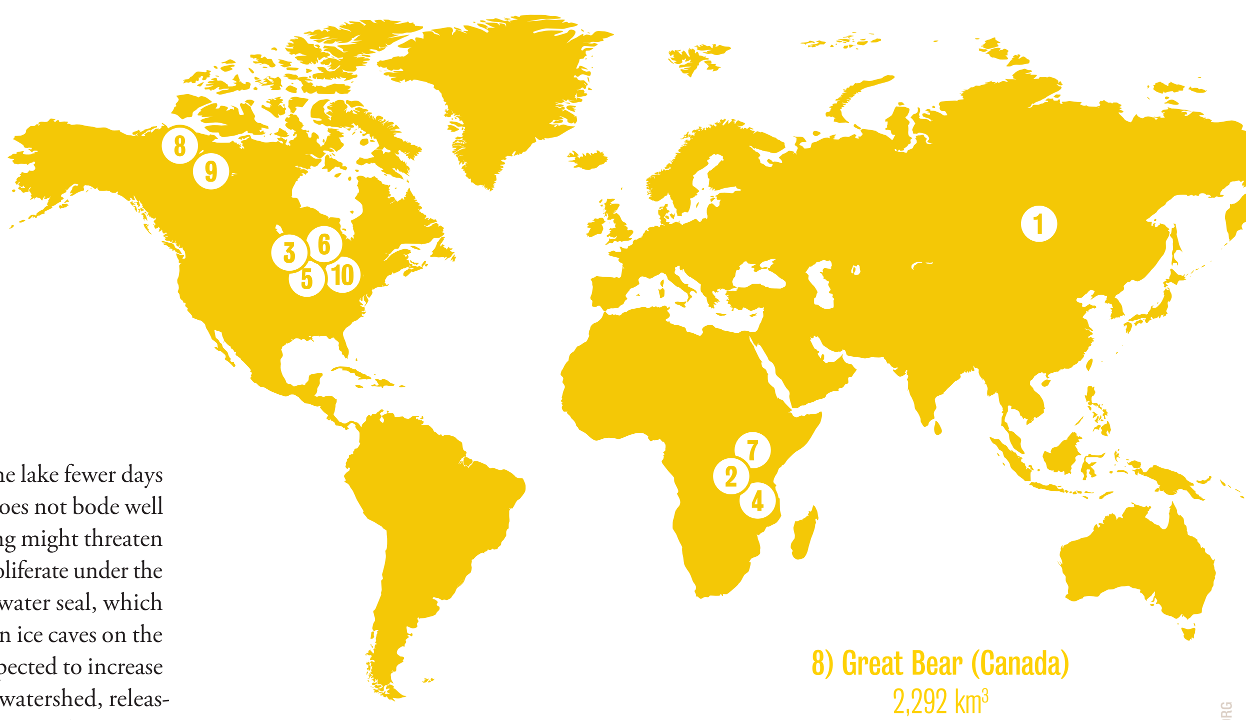
3) Superior (U.S. & Canada) 12,100 km^3

4) Malawi (Malawi, Mozambique & Tanzania) 7,775 km^3

5) Michigan (U.S.) 4,920 km^3

6) Huron (U.S. & Canada) 3,540 km^3

7) Victoria (Tanzania, Uganda & Kenya) 2,760 km^3



8) Great Bear (Canada) 2,292 km^3

9) Great Slave (Canada) 2,088 km^3

10) Ontario (U.S. & Canada) 1,640 km^3

DATA SOURCE: WORLDLAKES.ORG

change in chemistry." If climate change creates such alterations, Malawi, with the most diverse fish community on Earth, could lose some of its more than 1,000 species of sunfishlike cichlids.

Turns out that's just the tip of the iceberg. Four hydroelectric dams downstream of the lake supply 90 percent of Malawi's electricity. The country is considering proposals to increase water withdrawals from Malawi for irrigation. Climate change aside, "the level of irrigation they're talking about could result in the level of the lake dropping to the level of no outflow rather frequently," says Johnson. "It would have dramatic and immediate economic impact on the country."

Johnson and Malawian colleagues have applied for funding from the National Science Foundation to determine how best to share water between irrigation and hydropower and to determine circumstances under which one should take precedence over the other.

"There are also implications for tourism. There are implications for fisheries in the lake," says Johnson. "There are a lot of very complex questions to be addressed."

Cooperation and Differences

International cooperation opens new vistas in the quest to protect the world's great lakes. But collaboration also reveals cultural differences among people who live by these lakes.

> Disregard for clashing perspectives can lead to the failure of aid and collaboration over the management of fish, lakes and other resources.

Consider Lake Victoria, bordered by Tanzania, Kenya and Uganda. Second-largest freshwater lake in the world by area—bigger than Lake Huron or Michigan—Victoria is only 260 feet at its deepest. It once had a tremendous number of cichlid fish species, many of which provided subsistence to the people on its shores. But none was large enough to support a commercial fishery. So during the 1950s, fish managers introduced Nile tilapia and Nile perch, a freshwater giant that can weigh more than 400 pounds. The effect on native cichlids was disastrous. With habitat changes, such as the spread of exotic water hyacinth across shallow bays, Nile perch and tilapia were blamed for the extinction of 150 species of cichlids. Says MacIntyre at UC–Santa Barbara, "It was considered one of the largest ecological catastrophes to ever happen." The International Union for the Conservation of Nature has labeled the Nile perch one of the world's 100 most invasive species.

Yet local residents see it differently. The two exotic fish support a commercial fishery that lands $590 million of fish a year, including the annual export of $250 million worth of Nile perch—and this in an area with an annual income of about $1,200, where the average fishing boat consists of a two-man canoe. Victoria fishing employs 2 million and provides household incomes to nearly 22 million. According to the Lake Victoria Fisheries Organization, "Lake Victoria is the most productive freshwater

ABOVE: Canada's Great Slave Lake, like all large lakes, provides life support to a spectrum of unique natural communities. PHOTO BY CHRIS FOURNIER // BELOW: Most of the animal protein consumed by people living along Lake Malawi's shores comes from fish such as these native usipa. PHOTO BY ALEX BRAMWELL

fishery in Africa… an immense source of income, employment, food and foreign exchange for East Africa."

"On the African lakes, fish production is everything," says Dobiesz. U.S. biologists "look at the health of our systems as how well they mirror historic populations. In Africa, they consider healthy ecosystems to be ones that provide them with a lot of fish."

Disregard for clashing perspectives can lead to the failure of aid and collaboration over the management of fish, lakes and other resources. As Dobiesz notes, some non-governmental organizations "exist solely through support of donors from outside of Africa who contribute financial assistance for specific community projects. Such groups can alienate the local community by ignoring social norms and traditional structures."

Dobiesz recalls walking with a Ugandan researcher who was in the United States to help with the study of ecosystem health. At one point, Dobiesz explained the American conservation concept of catch-and-release fishing.

The Ugandan scientist stopped, dumbfounded. "I could never explain that to anyone in Africa," she stammered. "No one would ever take the time to catch a fish and throw it back. If they didn't need it for dinner, they would give it to someone who did. Or they would sell it to someone. But they would never, ever throw it back."

If research will continue to inform and benefit management of the world's big lakes, researchers will have to be keenly aware of the values and needs of the people living on the shores of those lakes.

GREG BREINING writes about travel, science and nature for *Momentum*, the *New York Times* and many other publications. He paddled around Lake Superior to write the book *Wild Shore: Exploring Lake Superior by Kayak*.

GREAT LAKES VIDEO
Learn about Lake Superior and climate change:
environment.umn.edu/momentum/webex

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MAKING THE MOST OF WATER

by ASHLEY KUEHL

EVERY PERSON ON THE PLANET NEEDS FOOD TO LIVE. And as the world's population grows, so does the size of that demand. But producing food involves more than just planting seeds. Agriculture requires water, and quite a lot of it. How can we make sure Earth's finite supply of water is best apportioned to grow the growing amount of food we'll need?

Scientists know how many calories a person needs to consume and how many people need to eat those calories. What if we could predict precisely how much water is needed to produce one calorie of food? And what if we could use exactly that quantity of water to produce it?

Kate Brauman, a postdoctoral fellow with the Institute on the Environment's Global Landscapes Initiative, hopes to answer those questions. By comparing global maps of precipitation, managed irrigation and weather patterns with the yields of 16 common crops, Brauman is learning just how much water is required to grow different kinds of food in different places.

GLI combines statistical information from various sources to create global maps of crop yields. "Take satellite imagery, which tells you where cropland is but not what's being grown there, and crop census data, which tells you what's being grown in a country but not where," Brauman says. "We're bringing these together to spit out maps that say, this is what is being grown where."

Brauman's role in the initiative is to add a water element by comparing the global crop yield data with water usage data. Our instincts tell us, Brauman explains, that drier locations need more water and wetter locations need less water to produce the same yields. To quantify this, she has divided the planet into 25 climate "bins," based on average annual precipitation and a measure of average annual evapotranspiration (movement of water from plants into the air). Places with similar climates fall into the same bins, allowing Brauman to compare crop yield data from far-flung locations.

Brauman uses this approach to map locations of irrigated crops, the quantity of water added, and each crop's yield. The maps can show "yield gaps"—locations where more crops could be grown. So far, Brauman says, irrigation management appears to play as big a role as climate in crop water use.

Brauman's research leads to more questions. For example, if farmers use precisely the needed amount of water to grow a crop, will the soil remain healthy? Brauman points out that plants take only the water and nutrients they need from soil, leaving salts behind. Here in Minnesota, rain and snowmelt flush salts out of the soil every year. But in a drier climate, such "perfect irrigation" could render the soil unusable.

Many questions and details remain, but if scientists can figure out how to best use our limited global water supply without sacrificing water quality, they can increase the likelihood of feeding a growing population for years to come.

ASHLEY KUEHL is a freelance writer from Minneapolis. She has written about sustainability and the environment for *Twin Cities Daily Planet* and *Momentum*.

IMAGINE A WORLD **WITHOUT** OIL

THE WORLD'S OIL ADDICTION

WORLD CONSUMPTION

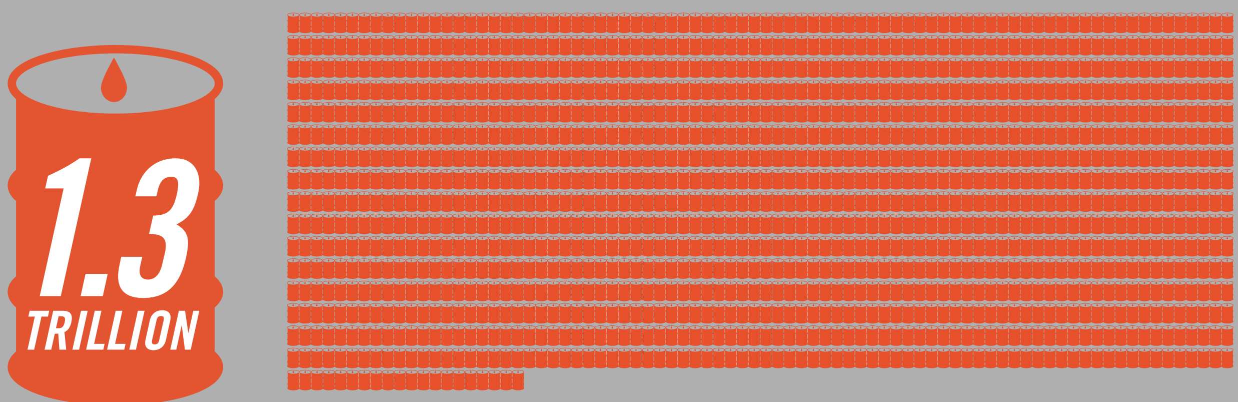
Currently, the world consumes more than 85 million barrels of oil per day. That amounts to nearly 31.6 billion barrels annually.

= 1 MILLION BARRELS CONSUMED

WORLD RESERVES

According to the U.S. Energy Information Administration, there are fewer than 1.3 trillion barrels of crude oil left in the world oil reserve.

= 1 BILLION BARRELS



TIME LEFT WITH OIL

If we continue at this same rate of consumption and the current reserves of crude oil neither diminish nor increase, we would have enough oil to last the world 41 more years.

41
YEARS

CONSUMPTION

TOP CONSUMERS

Below are the top global consumers of oil, showing their individual shares of energy from oil as well as the number of barrels consumed per day.

= 1 MILLION BARRELS CONSUMED PER DAY

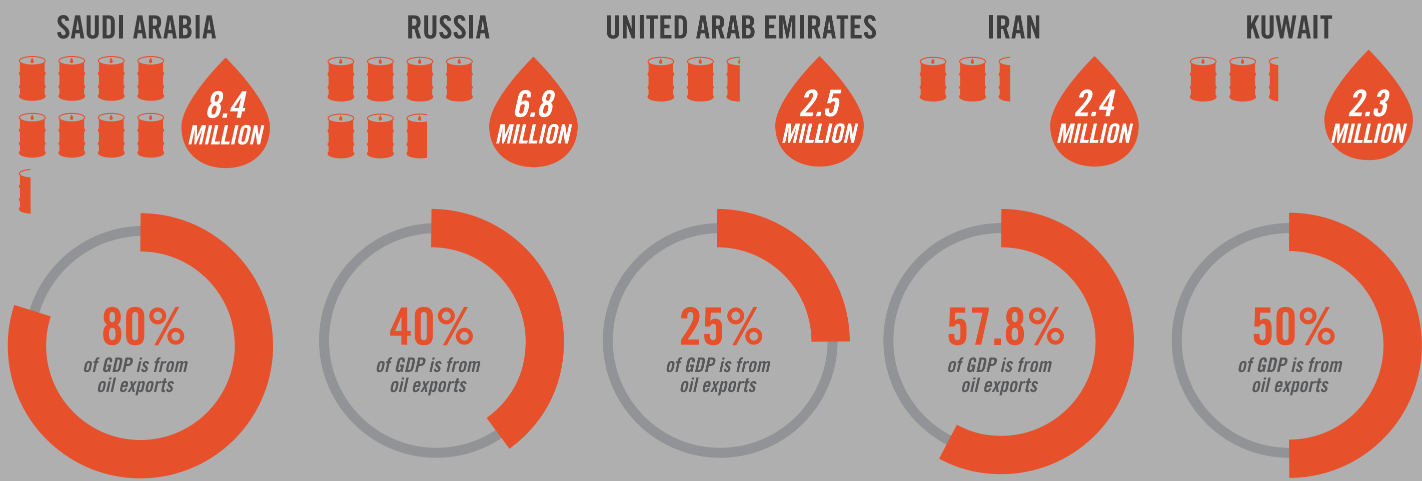
Country	Share of energy consumed that comes from oil	Barrels consumed per day
UNITED STATES	35.3%	19.5 MILLION
CHINA	19%	7.8 MILLION
JAPAN	45%	4.8 MILLION
INDIA	23.7%	2.9 MILLION
RUSSIA	37%	2.9 MILLION
GERMANY	32%	2.6 MILLION
BRAZIL	50%	2.5 MILLION
SAUDI ARABIA	52%	2.4 MILLION
CANADA	32%	2.3 MILLION
SOUTH KOREA	45%	2.2 MILLION

THE EFFECTS

$ EFFECTS ON THE ECONOMY

Nations dependent on oil exports could see their economies collapse. Witnessing millions of jobs lost, these nations would be most prone to civil unrest and war.

= POTENTIAL JOB LOSS



EFFECTS ON TRANSPORTATION

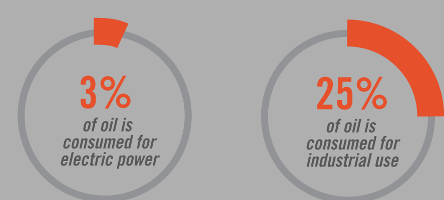
Transportation accounts for 66% of our oil consumption. If the world's oil supply were to dry up, transportation would all but cease. In addition, other industries would be drastically affected: shipping, air travel, food industries and almost any other industry that requires its workers to travel to and from work.

Only about 30 percent of the energy that cars consume from gas is converted into mechanical energy. The rest of the energy is waste heat.

8.8 out of 10 Americans commute to work using a car.

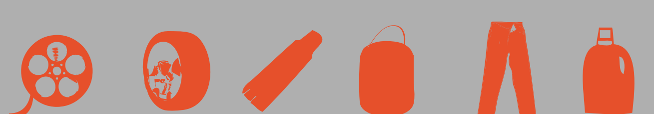
EFFECTS ON ELECTRICITY

While a majority of our electricity comes from natural gas and coal, we produce and procure these resources through machines that use oil. In a world lacking oil and alternative energy sources, electricity would become scarce, causing simple everyday conveniences—such as frozen food—to be a thing of the past.



EFFECTS ON CONSUMER PRODUCTS

Many consumer products depend on oil either as a primary ingredient or through machines that are powered by oil. Below are just some of the thousands of items created from oil.



WHAT CAN WE DO?

IMPROVE CAR MILEAGE

= 100,000 BARRELS SAVED

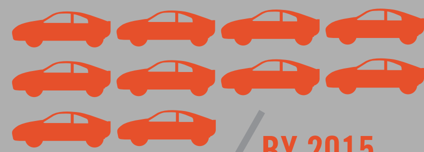
The first step to decreasing our dependence on oil is to make our cars more fuel efficient and get better fuel mileage. By simply setting stronger standards and forcing car manufacturers to average at least 60 mpg by 2025, we could save nearly 3 million barrels of oil per day in 2030. That is nearly three times the amount of oil we import from Saudi Arabia.

PER DAY 2030

THE ELECTRIC CAR

= 100,000 ELECTRIC CARS

President Obama has challenged the nation to put 1 million electric cars on the road by 2015. Since transportation consumes the largest percentage of crude oil, investing and encouraging electric and alternative fuel vehicles could help to drastically reduce our oil needs.



BY 2015

FUND ALTERNATIVES

Of course, the most important step to kick our oil addiction is investing in new technologies and alternative fuels. Using incentives such as feed-in tariffs will help boost renewables. Feed-in-tariffs are "the price per unit of electricity that a utility or supplier has to pay for renewable electricity from private generators. The government regulates the tariff rate." This may help cover the comparatively higher cost of renewables.

SOLAR WIND WATER

SOURCES: EIA.GOV / CIA.GOV / INFLATIONDATA.COM / NATGEO.COM / THEINDEPENDENT.COM / RANKEN-ENERGY.COM / LOWIMPACTLIVING.COM /

"OIL SHORTAGES? IT'S HAPPENED BEFORE AND IT WILL HAPPEN AGAIN" BY RONALD R. COOKE / ASSOCIATEDCONTENT.COM / NYTIMES.COM

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FACING UP TO PHOSPHORUS

WE CAN'T LIVE WITHOUT THIS ESSENTIAL ELEMENT—YET AT THE SAME TIME WE'RE HAVING AN INCREASINGLY HARD TIME LIVING WITH IT. WHAT IN THE WORLD ARE WE GOING TO DO? BY TIM LOUGHEED

PHOSPHORUS PELLETS MADE FROM WASTEWATER
PHOTO COURTESY OF OSTARA NUTRIENT RECOVERY TECHNOLOGIES INC.

In Aldous Huxley's dystopian *Brave New World*, citizens contribute to society even after death. As gases exit a crematorium smokestack, a special device recovers phosphorus—"more than a kilo and a half per adult corpse." The recovered phosphorus then fertilizes all manner of plant life, which thrives on this vital nutrient recycled from the remains of the dead.

Huxley's account is remarkable because it was written in the early 1930s, when far less public attention was devoted to the supply of natural resources. In fact, the full potential of phosphorus would be demonstrated several decades later. Its targeted use fueled the Green Revolution of the 1960s and 1970s, which dramatically improved crop yields and helped minimize the proportion of the world's population remaining underfed.

Farmers around the world have come to depend on manufactured inorganic fertilizers containing key plant nutrients phosphorus, nitrogen and potassium to enhance soil fertility, especially in the otherwise poor soils of most tropical settings. But while all three are relatively abundant in nature, practical sources of phosphorus to make these fertilizers could be exhausted just a few decades from now. That prospect, which remains a source of heated debate, has spurred a drive to recover the significant quantities of this element that disappear in the waste streams of cities and farms. Such recovery would have a bonus benefit: Even without the threat of shortages, minimizing the disposal of phosphorus is increasingly key to preventing degradation of valuable freshwater resources.

MOMENTOUS SHIFT

The availability of nitrogen, phosphorus and potassium in soil is a limiting factor in plant growth. The limitation imposed by phosphorus is the strictest, based on the amount of this material that plants take up and concentrate. Since all living organisms incorporate phosphorus in varying chemical combinations, modest amounts are relatively easy to obtain from biological sources. Spreading animal manure on fields is among the oldest known ways to add phosphorus to a crop. Urine can also be effective. Guano from birds and bats is exceptionally rich in this regard, as is bonemeal.

Yet even as Huxley was writing, and certainly by the time the Green Revolution rolled around, such organic inputs were no longer sufficient to match the scale of agricultural output. As a result, most of the phosphorus that ends up on fields today comes not from organic materials, but from inorganic phosphates extracted from geological deposits.

This distinction makes no difference to crops. For our society and economy, on the other hand, the shift has been nothing less than momentous.

"Today, we are effectively dependent on phosphorus from mined phosphate rock," says environmental scientist Dana Cordell, a research principal at the Institute for Sustainable Futures in Sydney, Australia. In many places, such as Brazil or central Africa, phosphate-based fertilizers are essential to maintaining crop yields and ensuring domestic food security. And that, Cordell says, spells trouble. For her, inorganic phosphates represent a nonrenewable resource that contrasts sharply with traditional sources of phosphorus such as manure, which are integrated into a natural environmental cycle. And because they're only found in certain areas, global politics comes into play.

Adding phosphorus to nutrient-poor soils can dramatically enhance crop production. Maize plants in the foreground of this photo taken on Brazil's cerrado are growing on unsupplemented soil; the taller ones behind them received phosphorus fertilizer.
PHOTO BY D.M.G. DE SOUSA

"Increasing environmental, economic, geopolitical and social concerns about the short- and long-term use of phosphate rock in agriculture means there is a need to reassess the way crops obtain their phosphorus and humanity is fed," she says.

PEAK PHOSPHORUS?

Some, including Cordell, see a limited future for the conventional mining of phosphates. Easily obtained, high-quality deposits of this material

Some 51 billion of the estimated 60 billion metric tons of phosphate rock reserves on Earth are found in one country, Morocco. This phosphate mine near Casablanca was photographed in the early 1990s. PHOTO BY YANN ARTHUS-BERTRAND/CORBIS

will become harder to find, and its price could be expected to rise accordingly. Production should ultimately peak as commercially viable supplies become more limited, reducing the amount of phosphorus available for use as fertilizer. This reduction would be reflected by declining agricultural production in some parts of the world, along with the specter of mounting hunger.

What remains a point of contention is exactly when such problems might arise. Cordell and others insist that this scenario could play out in a very few decades, as the quality of available phosphate begins to decline.

"Importantly, this means increasing energy and other resources (like sulfur) are therefore required to mine, process and extract the same nutrient value from phosphate rock while simultaneously generating more waste," she says. "Further, the global trade of phosphate commodities to the farm gate currently relies on fossil fuel energy, yet in a carbon-constrained future, shipping millions of tons of phosphate rock and fertilizers around the globe may no longer be appropriate or possible."

Opponents of this view harken back to doomsday forecasts framed decades ago by prominent analyses like *The Limits to Growth* or *The Population Bomb*. Economic and environmental disasters that should already have overwhelmed us by now have instead been postponed indefinitely, thanks to changes in our behavior, economic policy or technological capabilities. Discussion of those disasters undoubtedly prompted at least some of the necessary changes, and could do so again in the case of phosphorus.

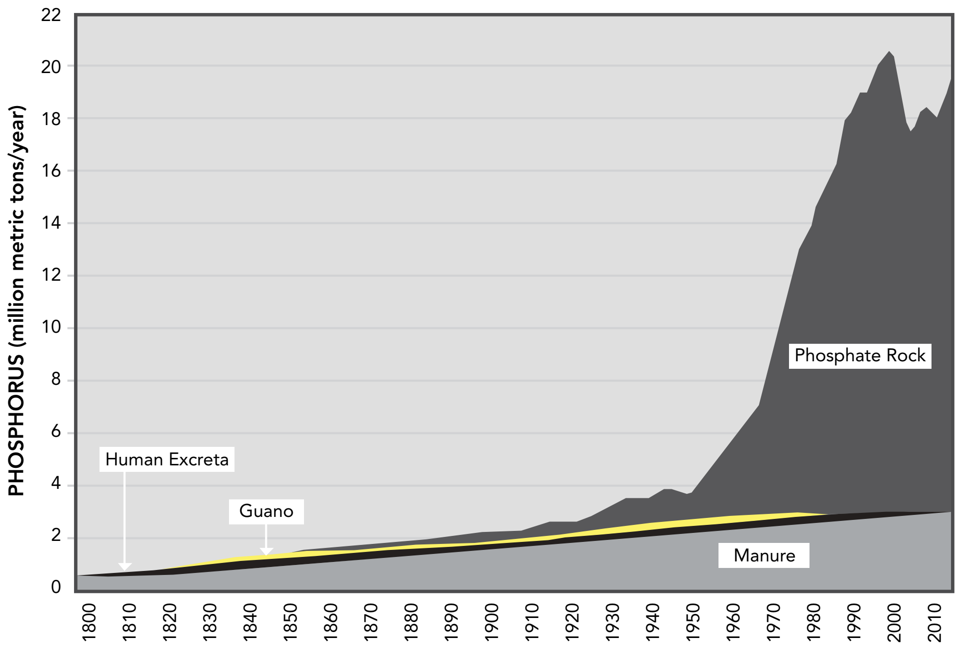
This optimistic perspective benefited from a 2010 revision of estimates of the world's phosphate reserves. New figures from the International

Fertilizer Development Center raise the estimate from 16 billion metric tons to more than 60 billion metric tons. The author of that report, geologist Steven Van Kauwenbergh, insists that this finding should put an end to any immediate concerns about peak phosphorus.

"Based on this estimate," he says, "at current rates of production, phosphate rock reserves to produce fertilizer will be available for 300 to 400 years."

At the same time, Van Kauwenbergh cautions that the sources of information used for this estimate tend to be limited, provided primarily by industrial interests. "A collaborative effort by phosphate rock producers, government agencies, international organizations and academia will be required to make a more definitive estimate of world phosphate rock reserves and resources," he concludes.

Historical Global Sources of Phosphorus Fertilizers (1800–2010)



Adapted from Cordell, D.; Drangert, J-O. and White, S. (2009). The story of phosphorus: Global food security and food for thought. *Journal of Global Environmental Change* 19(2):292–305.

Before the Green Revolution, most of the phosphorus used to boost crop growth came from animal waste. Today's farmers rely mainly on phosphate rock mined from a few key hot spots around the world.

BRAVE NEW SOURCES

Even if phosphate is more abundant than previously thought, the distribution of reserves poses a big challenge.

Morocco alone appears to control no fewer than 51 billion of the estimated 60 billion metric tons of phosphates, some 84 percent of the total. The rest is found in various places in much smaller amounts, with 6 percent in China, 1 percent in the U.S., 1 percent in Jordan and the remainder spread among the rest of the world's nations.

These relatively limited supply lines could be vulnerable to disruptions, as was demonstrated in 2008 when China imposed a 135 percent export tariff on its phosphate rock. This geopolitical context has been further complicated by Morocco's controversial occupation of Western Sahara since 1975, which has prompted some Scandinavian firms to protest by boycotting that region's phosphate exports.

In addition to political considerations, poor transportation links limit the volume of fertilizer reaching farmers in some countries, where a correspondingly high price makes this input all the less accessible. Even without the dire threat of peak phosphorus, as growing population boosts demand for food, intensifying competition along narrow international supply lines could place fertilizers beyond the reach of many more farmers.

EVEN WITHOUT THE DIRE THREAT OF PEAK PHOSPHORUS, AS GROWING POPULATION BOOSTS DEMAND FOR FOOD, INTENSIFYING COMPETITION ALONG NARROW INTERNATIONAL SUPPLY LINES COULD PLACE FERTILIZERS BEYOND THE REACH OF MANY MORE FARMERS.

Faced with this challenge, sources like that tapped in *Brave New World* could take on a fresh appeal. In fact, though it does not yet extend to crematoria, phosphorus recovery is not consigned to science fiction.

One promising technology is a chemical reactor that can be installed in municipal wastewater streams, where human urine provides a rich supply of raw material. Urine forms the basis of ammonium magnesium phosphate, a white crystal known as *struvite*. Struvite cakes on the walls of sluiceways and sewers, hardening into a concrete-like consistency that is onerous to remove.

Struvite, if it can be extracted in a pure form, offers the basis for an effective fertilizer. For example, an extraction technology produced by Vancouver-based Ostara Nutrient Recovery Technologies Inc. has been installed in cities in Canada, the U.S. and the UK. The system, like others, aspires to provide a cost-effective means of capturing struvite for agricultural use.

THE OTHER HALF

The other half of the phosphorus predicament, ironically, is a problem of localized overabundance. Soils in many parts of North America have naturally high levels of phosphorus. Add too much more in an attempt to boost crop yields, and nutrients drain off the land to fertilize lakes and rivers. What often follows is the proliferation of algae in these waters, which then become oxygen-poor and inhospitable to plant or animal life. This process, known as *eutrophication*, can compromise aquatic ecosystems.

"We have understood the causes of eutrophication for more than 40 years, while the drivers have gotten worse," says Stephen Carpenter, a professor at the University of Wisconsin's Center for Limnology in Madison. "Increased planting of corn, increased livestock numbers and increasingly variable precipitation due to climate change are principal drivers of increased eutrophication. We decreased the discharge from sewage treatment plants, but at the same time the runoff of manure and overfertilized soil became much worse."

Carpenter has been studying eutrophication since the mid-1970s, when the high-profile damage to Lake Erie shamed detergent manufacturers into lowering the phosphate content of their products. By the late 1990s, he observes, researchers were finding most of the ongoing eutrophication in North America was due to phosphorus runoff from farms. Most recently he considered what the ultimate planetary boundary might be for phosphorus discharge into the environment, a matter he explores as co-author of a paper appearing in the February 2011 *Environmental Research Letters*.

That paper argues that the boundary for the discharge of phosphorus into freshwater has already been exceeded. At the same time, many parts of the world remain in urgent need of phosphorus in order to be able to feed themselves. Carpenter suggests that regions with a surplus of phosphorus could solve two problems at once by packaging that surplus in the form of struvite for markets elsewhere.

"Midwesterners are rich in phosphorus, but they also suffer lots of toxic algae blooms and fish kills," he says. "Technologies to convert manure to lightweight [high-phosphorus] materials would help cure eutrophication in the Midwest while curing hunger in Africa."

As straightforward as that objective might appear to be, it conflicts with the ruthless economics of modern agriculture. According to Carpenter's co-author, Elena Bennett, large-scale livestock operations can leave little financial room for investing in technology to recover phosphorus, as the expenses associated with recovery equipment will not necessarily be recouped by sales of the resulting product.

For much of human history, cow manure served as a valuable source of phosphorus for fertilizing crops. Today the concentration of cattle in feedlots creates a localized overabundance of the nutrient, transforming it from treasure to trouble.
© ISTOCKPHOTO.COM/MAUROSCARONE

"We've moved from a system a couple of hundred years ago where you had a couple of cows and a couple of chickens and some corn, and so the manure was a useful resource," explains Bennett, an assistant professor at McGill University's Department of Natural Resource Sciences. "Now, things are just out of whack at the scale that we operate."

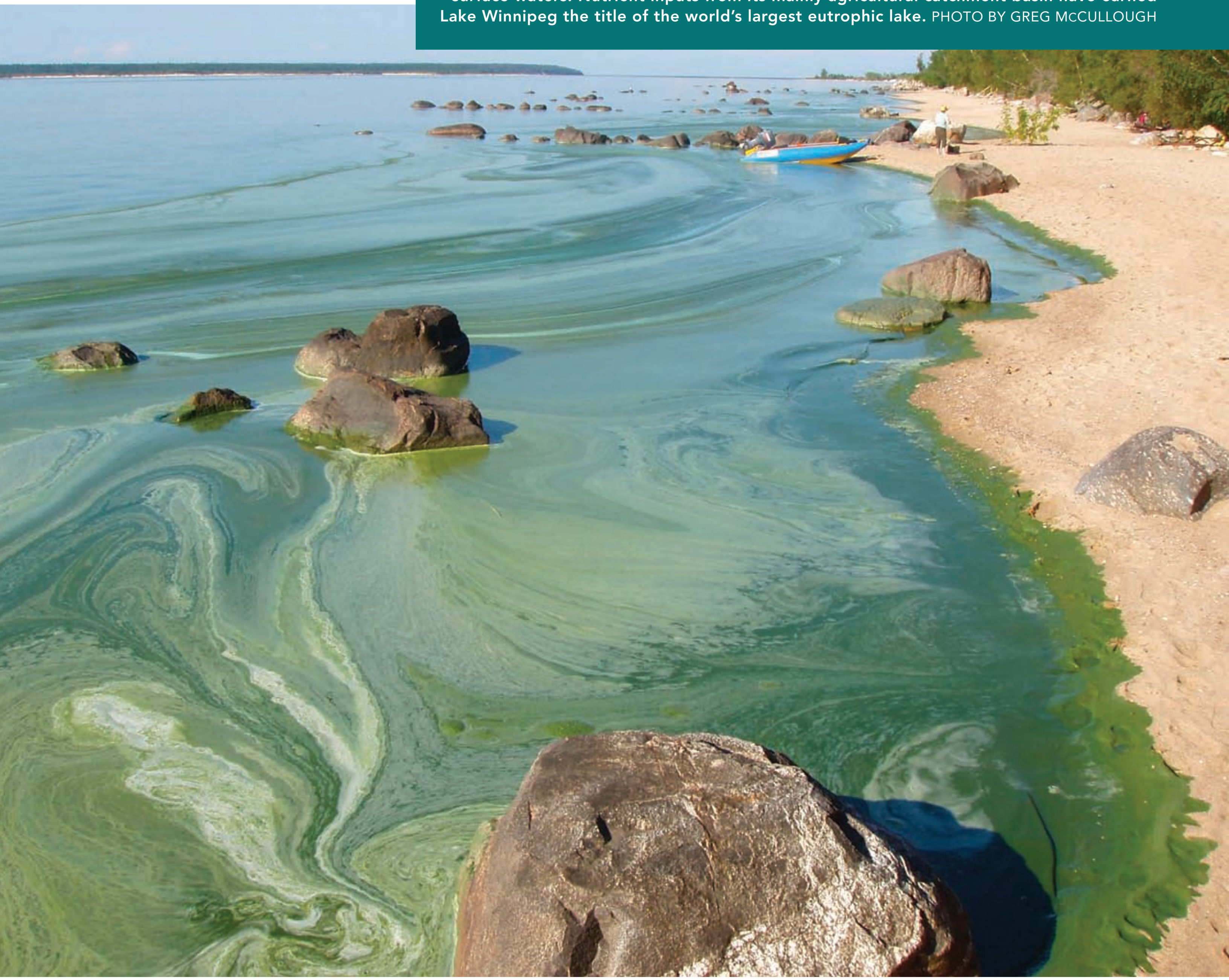
That doesn't mean that phosphorus removal is uneconomical, however. Bennett maintains that the cost of reducing phosphorus discharge should be weighed against the value of services provided by the environment under threat. Depending on the site in question, those services could include clean drinking water, recreational opportunities or hydroelectric power generation.

"This isn't about the natural world versus the developed world," insists Bennett. "This is about nature providing us with all these things, and some of those things it provides better when it's in a natural state and other things are better in a built state. If we can understand which states provide which amounts of which services, then we can start making more informed decisions."

WETLANDS TO THE RESCUE

This principle is being put forward to deal with the specific challenge posed by Lake Winnipeg, which has been touted as the world's largest eutrophic lake. That dubious honor stems from the lake's role as a catchment basin for four Canadian provinces and four U.S. states, concentrating soil runoff in this primarily agricultural region. According to the International Institute for Sustainable Development, based in the city of Winnipeg, much of that runoff travels unimpeded into the lake because coastal wetlands have been drained for farming.

IISD project manager Vivek Voora says that convincing farmers to leave wetlands in place to capture phosphorus and other nutrients from runoff rather than allow them to fertilize the lake amounts to competing with the value of those wetlands as planted fields. Delta Waterfowl, a longstanding Manitoba organization dedicated to preserving marshes for hunting, tries to match that value dollar for dollar with financial compensation to farmers who set aside wetlands. But as the price of some crops rises, this amount may not remain competitive with other uses for the land.



Phosphorus leached from soil, vegetation and manure stimulates the growth of algae in surface waters. Nutrient inputs from its mainly agricultural catchment basin have earned Lake Winnipeg the title of the world's largest eutrophic lake. PHOTO BY GREG McCULLOUGH

"We need to find a way to show farmers that managing a wetland is profitable," Voora explains. "It will provide money in your pocket."

Over the last few years, Voora has explored how natural wetlands could take part in a novel biological economy. Plants such as cattails could be harvested for conversion into bioplastics, or pelletized to become fuel. Meanwhile, the intact wetland will sop up most of the nutrients that would otherwise reach the lake.

In this sense, Voora points out, wetlands function as important pieces of ecological infrastructure. They may not be as focused and efficient as the kind of infrastructure cities could use to retrieve phosphorus from their wastewater for use elsewhere, but they can provide crucial services on farms where such built infrastructure is unlikely to appear.

"A nutrient that is so fundamental to the economy of this particular region," he says. "For us to be wasting it, for it to end up in water bodies and causing environmental problems, doesn't make a bit of sense."

TIM LOUGHEED has worked as a freelance writer in Ottawa, Canada, since 1991. A past president of the Canadian Science Writers' Association, his work covers a broad range of topics in science, technology, medicine and education.

THINKING ABOUT THE IMPLICATIONS BEFORE WE FORMULATE NEW MATERIALS CAN PREVENT A PLETHORA OF HUMAN AND ENVIRONMENTAL ILLS.

BY ELIZABETH GROSSMAN

CHEMISTRY GOES GREEN

In the decades since the publication of Rachel Carson's environmental classic *Silent Spring,* since the incidents of pollution that caused the Cuyahoga River to catch fire in 1969 and contaminated residents of Love Canal in the 1970s, our knowledge of how synthetic chemicals—chemicals that are made in laboratories but not found in nature—make their way into the environment and how they interact with living cells has grown remarkably.

We now know that many such chemicals enter the environment, not only from smokestacks, drainpipes, leaky storage tanks and waste sites, but also as they migrate from furniture, textiles, building materials, electronics, toys, personal care products, packaging and many more manufactured goods we encounter every day. As a result, many of these chemicals are present in indoor air and dust. Many are traveling the global environment with air and ocean currents. Many are in the food web and in our bodies.

At the same time our understanding of the sources of chemical exposure has been expanding, so has our knowledge of how chemicals behave biologically. Since well before the publication of *Silent Spring,* scientists have been aware of the potential adverse environmental and health effects of industrial chemicals. Attention to these impacts typically focused on acute and immediate effects resulting from high levels of exposure. But we now know that many widely used synthetic chemicals can interact with living cells at very low levels of exposure in ways that produce profound effects on development, metabolism, neurological function, reproduction and other vital body systems, sometimes affecting more than one generation. Almost every week, new scientific studies are published documenting adverse health effects of synthetic chemicals such as bisphenol A, brominated flame retardants, phthalates, persistent pollutants or endocrine disruptors—chemicals most of us encounter daily.

The discovery that our lives are filled with so many potential sources of exposure to chemicals with so many subtle but significant impacts has prompted the need for a pollution prevention strategy that goes well beyond putting filters and scrubbers on chimneys or treating wastewater. It has catalyzed the creation of a new approach to designing molecules that aims to prevent problems from occurring in the first place: green chemistry.

RADICAL DEPARTURE

The most fundamental principle of green chemistry is that the best way to prevent harmful chemical pollution is to design materials that are inherently environmentally benign and safe for human health. Green chemistry works toward this goal by using resources efficiently, eliminating use of inherently toxic ingredients and chemical combinations, eliminating waste and

WHAT'S THE PROBLEM?

PLAIN AND SIMPLE, IT'S PUTTING ATOMS TOGETHER IN WAYS NATURE HAS NOT—AND SO DOESN'T KNOW HOW TO HANDLE. OVER THE DECADES, SCIENTISTS HAVE FORMULATED ENTIRELY NEW COMPOUNDS TO MAKE OUR CLOTHES WHITER, OUR SKIN SOFTER, OUR PLASTICS MORE PLIABLE, OUR PANS LESS STICKY, OUR CARPETS LESS VULNERABLE TO STAINS AND MORE, WITHOUT CONSIDERING THE FULL RANGE OF HOW THESE NOVEL MOLECULES WILL BEHAVE IN NATURE—OR IN US. NOW WE'RE DISCOVERING THAT THE CONSEQUENCES CAN STRAY FAR BEYOND WHAT WE EVER IMAGINED. WHEN LET LOOSE IN THE ENVIRONMENT, MANY OF THESE MOLECULES CAN BECOME SERIOUS HEALTH HAZARDS, KNOCKING BIOLOGICAL SYSTEMS OFF BALANCE IN WAYS THAT CAUSE CANCER, REPRODUCTIVE DISORDERS, DEVELOPMENTAL DISABILITIES AND OTHER PROBLEMS.

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hazardous by-products, and minimizing use of energy throughout a product's entire life cycle.

While this seems like common sense, it represents a radical departure from the status quo.

Asking synthetic chemists—scientists in the business of creating new molecules—to think about a molecule's biological and ecological behavior and its environmental footprint adds an entirely new dimension to their work. Historically, such considerations have been absent from synthetic chemistry. Chemists are not required to have any formal training in toxicology or other environmental health science that would enable them to understand ecological impacts at the molecular level. John Warner, president and chief technology officer at the Warner Babcock Institute for Green Chemistry, has said of his early career as a commercial chemist, "I have synthesized over 2,500 compounds but have never been taught what makes a chemical toxic."

Warner and Paul Anastas, assistant administrator for the U.S. Environmental Protection Agency's Office of Research and Development, are widely regarded as the founders of green chemistry. In their book, *Green Chemistry Theory and Practice,* Anastas and Warner outlined 12 principles of green chemistry, guidelines for working chemists to consider as they set out to design new compounds to minimize—and ideally eliminate—the risk of creating molecules that will threaten the health of humans or the environment.

But Warner points out these principles are just the start. "We have to realize [that bringing green chemistry into practice] is an endless process," he says.

Understanding what makes a chemical product safe is the challenge of green chemistry, Lynn Goldman, dean of George Washington University School of Public Health and Health Services, told attendees at the American Chemistry Society's 15th Annual Green Chemistry & Engineering Conference in Washington, D.C., in June.

Knowledge of how chemicals behave has grown well beyond that on which our current system of regulating chemicals was based, Goldman explained. To understand what makes a molecule safe or toxic, we now have to take into account endocrine active compounds, how environmental exposure to chemicals can alter how genes behave, and the many ways in which chemicals can interact with the various dynamic parts of living cells. To put this knowledge into practice, Goldman said, will require "new collaborations between clinicians, chemists, engineers and biologists."

FIRMLY ESTABLISHED

Since it was introduced almost 20 years ago, green chemistry has become firmly established as an approach to designing new chemical products and manufacturing processes in ways that make them less hazardous to human health and the environment.

EPA started a green chemistry program in the 1990s that supports research aimed at developing and promoting pollution prevention through the design and synthesis of nontoxic, resource efficient materials. For the past 16 years the agency has awarded Presidential Green Chemistry Challenge Awards to honor "outstanding examples of green chemistry." These have included new ways to synthesize ibuprofen, bio-based plastics, non-toxic adhesives, water-based high-performance paint and non-toxic chemical cleaning agents that can neutralize persistent toxics.

EPA's Design for the Environment Program is using green chemistry to support work to develop nontoxic commercial cleaning products, to assess alternatives to hazardous flame retardants and to find safe replacements for products based on bisphenol A. Green chemistry is also part of numerous individual state policies aimed at preventing exposure to hazardous chemicals, among them efforts in California, Maine, Massachusetts, Michigan and Washington. In Europe, chemicals management policies—among them the European Union directive known as REACH (Registration, Evaluation, Authorization and Restriction of Chemical Substances)—are providing incentives for green chemistry innovation, and green chemistry education is being incorporated into university-level curricula in China and India.

In the United States, efforts are underway to improve chemists' ability to evaluate synthetic chemicals based on the many ways they can interact with living cells. Adelina Voutchkova of the Yale University Center for Green Chemistry and Green Engineering presented one example of such an evaluation tool at the ACS conference. Also at the conference, Raymond Tice, chief of the U.S. National Toxicology Program's Biomolecular Screening Branch, presented the new toxicology tools being developed by the NTP and National Institute of Environmental Health Sciences that will enable scientists in academia and regulatory agencies to evaluate chemicals for the wide range of behaviors green chemistry considerations demand.

Rich Helling, associate director of sustainability/life cycle assessment at Dow Chemical, says his company is training its research and development scientists to do "early screening" of new products and to consider materials from a perspective of "atom and energy efficiency, hazard reduction, and holistic design," and thus "pick more sustainable projects."

Green chemistry efforts at Dow have gone into producing a number of industrial chemicals, among them a bio-based plasticizer, explains Helling. They have enabled Dow to meet customers' requests for products that do not contain "particular chemicals of concern, such as phthalates and lead," says Helling. They have also gone into Dow's production of a new compound to replace a flame retardant that has been

Knowledge of how chemicals behave has grown well beyond that on which our current system of regulating chemicals was based.

discovered to be environmentally persistent and environmentally mobile. And in August, Dow for the first time publicly presented its new research and development sustainability footprint tool that is being applied throughout the company's R&D efforts.

"The concept of sustainable chemistry is a great framework for understanding how to approach things," says Helling. Improving the safety profile of a new process or product is "good process chemistry," he explains. Any process that is not less hazardous or less complex "slows down your research," he says.

NEXT: EDUCATION

"The case for green chemistry has been made," says Amy Cannon, executive director and co-founder with Warner of Beyond Benign, a nonprofit organization devoted to green chemistry education. "What is next? A more systematic approach that's really going to change the way we educate scientists."

Teaching future chemists what makes a molecule toxic is essential to advancing green chemistry, agrees Warner. "Without this we can't accomplish our goals."

Green chemistry advocates are approaching this at the professional level, fostering working partnerships between environmental health scientists and synthetic chemists through efforts such as the collaborations being facilitated by the nonprofit Advancing Green Chemistry. They're also pushing for change in education, creating new curricula for students beginning at the K–12 level and extending through and beyond college and university education.

Warner underscores that simply showing students and professional chemists examples of green chemistry products and asking them to learn the principles of green chemistry is not sufficient, however.

What's needed is an understanding of what makes molecules behave—how their chemical composition and structure influences their biological and physical behavior.

"It would be like showing examples of Russian poetry—an alliteration, an allusion, a time juxtaposition, all in Russian—to people who don't speak Russian and then asking them to write a Russian poem," he says. What's needed is an understanding of what makes molecules behave—how their chemical composition and structure influences their biological and physical behavior. Creating a molecule to perform a certain task (the traditional goal of synthetic chemistry) without considering the full range of its potential ecological interactions falls short of green chemistry's goals.

Marc Hillmyer and William Tollman are preparing chemistry students for careers in which green chemistry will be a given rather than a novelty. In 2010–11 the University of Minnesota faculty taught a three-credit course in green chemistry for chemistry majors. This information, Hillmyer says, is essential to training the next generation of scientists to create new materials that "don't have negative health consequences, will reduce our reliance on petroleum" and have what Hillmyer calls "programmed end-of-life designs." By this he means making new synthetic chemicals that are designed "in environmentally friendly ways to be recycled or reconstituted." Hillmyer, whose specialty is polymers, points out that it's important to "think about this at the front end" rather than after the fact—as shown by the impacts of countless extremely useful but hazardous chemicals.

Like Cannon and Warner, Hillmyer acknowledges that we don't yet have all the tools—educational or toxicological—that are needed.

"This is a great area for growth," he says. Filling this gap was part of the impetus for developing a green chemistry course that would be part of the general chemistry curriculum.

"We made a conscious choice to teach this to our chemistry majors," he explains. "We need to get this into the minds of people who are going to work for companies like Dow and DuPont."

Students seem to need no persuasion: "Our course was oversubscribed. We had to turn people away," says Hillmyer.

This fall, Cannon and Warner are teaching a course at Simmons College that Cannon says is "most likely the first toxicology course to be required of chemistry majors." Warner explains that what this class will teach is "mechanistic toxicology," which will begin to teach students "how to look at a molecule and know if it's toxic."

Warner uses the term "toxic" broadly, to include molecules that bind to DNA, are greenhouse gases or cause ozone depletion.

"If I could wave a magic wand, mechanistic toxicology would be the moral responsibility of anyone making a material," Warner says.

Clearly there are no magic wands. But the challenging process of what Anastas describes as "changing how we define goals and performance" to produce new molecules that are more environmentally benign, are more economically viable and will rival or outperform existing materials is clearly underway.

ELIZABETH GROSSMAN is the author of *Chasing Molecules: Poisonous Products, Human Health, and the Promise of Green Chemistry; High Tech Trash: Digital Devices, Hidden Toxics, and Human Health;* and other books. Her work has appeared in a variety of publications including *Environmental Health Perspectives, Yale e360, Scientific American, TheAtlantic.com, Salon*, the *Washington Post*, the *Nation* and the *Pump Handle*.

MORE ON GREEN CHEMISTRY:
environment.umn.edu/momentum/webex

Fuelish Choices

Brazil, biofuels and the ethic of sustainable development

by JOHN SHEEHAN

IN SPRING 2011, the Institute for Agriculture and Trade Policy invited me to participate in a fact-finding mission to Brazil as part of a dialogue on the indirect land use change effects of biofuels (known among policy wonks as "ILUC"). I jumped at the chance. For the past two years I have been caught up in the ongoing political and technical controversies that have swirled around this otherwise arcane concept. The invitation offered a chance to look at "ILUC on the ground," as the organizers aptly called our adventure.

What exactly is ILUC, and why is it so important? Put bluntly, ILUC is a reframing of the "food versus fuel" debate that has dogged the U.S. biofuels industry from its earliest days.

PHOTOS BY JOHN SHEEHAN

The central question about biofuels is an ethical one: Can we afford to divert farmland from its primary role as a provider of food, feed and fiber to one of also being a provider of fuel? ILUC transforms this into a climate change question: Can we afford to clear land for fuel production, in the process releasing stored CO_2 into the atmosphere? It's a clever way of turning an ethical debate into a "safer" and seemingly more tractable technical one.

At the heart of this "new" ILUC debate is Brazil. Many environmentalists believe that expanding demand for biofuels will lead to the clearing of the Amazon as well as the large and valuable savanna ecosystems found in Brazil. I can think of no better way to inspire honest dialogue about ILUC than to bring environmentalists, academics, farmers and biofuels entrepreneurs to Brazil—one of the hot spots of biofuels development, agricultural expansion and deforestation.

In that setting, I was struck by the stark contrast between what I now see as the sterile policy debate about ILUC and the harsh reality of the serious questions Brazilians face when they think about biofuels. The ethanol and biodiesel industries in Brazil put into sharp focus much deeper social and environmental concerns.

The Brazilian biofuels industry faces a deep political divide. You might call it "the big guy versus the little guy." For many activists in Brazil, biofuel is a tool for expanding "agribusiness"—an epithet they apply with disdain and distrust. In fact, union members and environmental activists we met with referred to sugarcane ethanol as "agri-fuel" rather than "biofuel." The reason? In Latin America and Europe, "bio" implies "organic" or "sustainable." For the activists, the economic, health and environmental damage and injustice they associate with agribusiness renders the use of the term "bio" in connection with agrifuels perverse.

When we looked at the growth of Brazilian agriculture in the state of Mato Grosso, many of us saw a miraculous transformation from an impoverished and unproductive farm system to a highly productive contributor to the Brazilian economy. Many in Brazil see, instead, a pernicious continuation of the concentration of wealth and power as farms consolidate.

To be sure, Brazil suffers from a tremendous disparity in wealth. Labor groups have pushed to establish small family-owned and -operated farms as a means of redistributing the land. Their vision of sustainable agriculture and biofuels is diametrically opposed to the vision promoted for the past four decades based on technology-driven, capital-intensive, large-scale production.

We visited a small farm co-op in Mato Grosso. The families working such farms seek a more equitable agrarian economy that is environmentally responsible and socially just. These people are not armchair environmentalists or "do-gooders." They are motivated by years of frustration and deprivation. When I asked one small-farm owner why he left his life as a paid worker on a large farm for this more risky and physically demanding situation, he answered quietly but firmly—dignity and a sense of control over his own life. Hard to argue with that.

It's easy for developed countries to demand that Brazil preserve its natural resources. But few countries have struggled to balance their economic welfare with stewardship of natural endowments as much as Brazil has. Don't get me wrong. Brazilians (like all of us) have a mixed record when it comes to achieving this balance. But they are at least trying.

I would suggest that interest in biofuels has heightened Brazil's awareness of the importance of protecting natural resources. But I don't want to give too much credit to the biofuels industry. The people of Brazil value their natural endowments.

Few people really get the meaning of sustainable development. The Brazilians are struggling to understand it and to live it. We can learn a lot from their struggle to balance the ethical, social and technical demands of sustainable development and the role biofuels should play in it. Our experience in Brazil has reinforced for me the idea that ILUC is just one aspect of sustainable biofuels, which in turn is a challenge that is fully subsumed by the bigger challenge of sustainable agriculture.

Brazil has demonstrated how a developing country can apply technology, capital, economy of scale and focused research and development to revolutionize its agricultural sector and improve quality of life for many of its people. This industrial model of agriculture has made Brazilian biofuels a success. But is there a place for the small family farm model in improving the lot of Brazil's people while meeting the global appetite for Brazil's farm products? Which approach will best address the concerns about biofuels-driven clearing of land? Which will lead to the most environmentally friendly use of our land to meet food and fuel needs?

A firsthand look at Brazil tells me that we have been missing the bigger question about biofuels—how to transform agriculture so it can maximize its contribution to sustainable development. In other words, how to achieve sustainable agriculture.

I started out criticizing ILUC for its one-dimensional take on sustainable biofuels. But what I love about ILUC is how it has forced us to look beyond ourselves as individual nations and beyond the narrow perspective of the biofuels industry itself. Ten years ago, I could not have imagined a policy debate about biofuels that would so urgently focus on broader global implications. It represents real progress.

In Brazil's Mato Grosso, the ILUC debate expands to include broader issues of ethics, politics and social justice as well as carbon balances.

From left: *industrial-strength infrastructure at a 1,500-hectare soybean farm; owner of a one-hectare farm; farmland traces a jagged line along the edge of remaining rainforest.*

PHOTO BY RHETT A. BUTLER / MONGABAY.COM

JOHN SHEEHAN is science director for the Institute on the Environment's Initiative for Renewable Energy and the Environment.

BEHIND THE SCENES
Read an in-depth version of this piece and view a slide show:
environment.umn.edu/momentum/webex

Mother Nature's Pest-B-Gone

George Heimpel is looking to little wasps to reduce the environmental impacts of pesticide use.

by MARY HOFF | photos by JOSH KOHANEK

IT WASN'T YOUR TYPICAL SUMMER JOB. While friends flipped burgers, babysat or worked on landscaping crews, George Heimpel spent his high school vacations rearing insects that eat other insects alive from the inside out.

The insects under his watch were parasitoid wasps, and the job, though exotic, was far from frivolous. Heimpel's employer, a California company called Beneficial Biosystems, sold the rice-grain-sized, people-friendly wasps for natural fly control. Released into barnyards or stables, the wasps would lay eggs inside fly pupae. When they hatched, the larvae would feast on the innards of their hosts, providing a sort of self-perpetuating pest control that obviated the need for toxic chemicals.

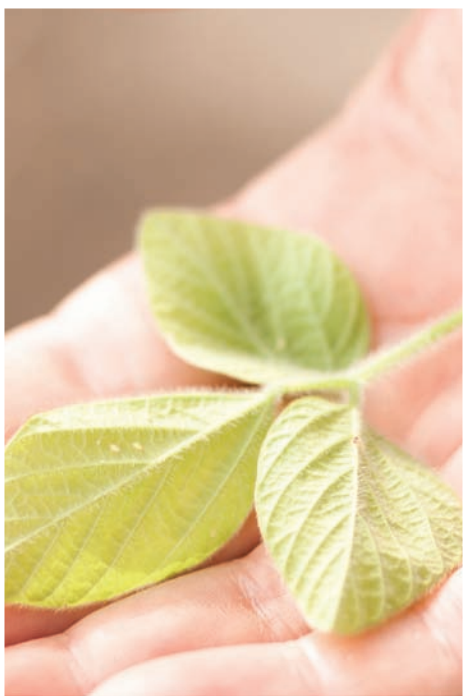
"I liked working with insects, I liked doing something that had the possibility for helping the environment and I liked the people there," Heimpel says. "It was fun."

As summer jobs sometimes do, this one stuck. Today, as professor of entomology in the University of Minnesota's College of Food, Agricultural and Natural Resource Sciences and Institute on the Environment resident fellow, Heimpel continues to spend much of his time working with parasitoid wasps in hopes of providing Earth-friendly ways to minimize insects' adverse impacts on people.

Heimpel's current area of focus is not fly-eaters, but wasps that attack tiny insects called aphids. Aphids are notorious competitors for human food supplies, cutting yields of crops by up to 50 percent in the case of bad infestations. The conventional way farmers reduce the toll is to spray infested fields with powerful pesticides, which not only kill their target but also have the potential to harm a variety of other species that get in their path, including honeybees, birds and fish.

In particular, Heimpel is homing in on control strategies for a relative newcomer to the North American pest scene: the Asian soybean aphid. Unheard of here before it showed up in a Wisconsin field in 2000, the aphid has spread so far that producers now spray tens of millions of acres of soybean fields—acres that previously needed no pesticides—each year.

Heimpel and colleagues have been testing Asian parasitoid enemies of the Asian soybean aphid in search of one that would, were it released into the environment, be able to keep the aphid in check without otherwise upsetting the ecosystem apple cart. The screening



process is understandably rigorous, and the bar set high to prove no possibility of harming native species before receiving government permission to release the nonnative wasps.

"We've been doing tests to learn how other insects might be affected by the release of these Asian parasitoids," Heimpel says. "The question is, do they pose a danger to native aphids?"

Five years into the project, the research team has gotten approval to release one parasitoid wasp species that has shown limited effectiveness in driving down soybean aphid populations. Several other species are undergoing safety testing in a quarantine laboratory.

Heimpel recently began exploring whether parasitoids might be good news when it comes to global warming as well. Working with Jason Hill, another IonE resident fellow who's an assistant professor of bioproducts and biosystems engineering in CFANS, he's comparing the carbon footprint of five different options for dealing with soybean aphids: three conventional pesticide treatments, a cropping strategy to reduce the aphid, and biological control using a parasitoid that serves as a natural control to soybean aphids in Asia.

In a separate study, Heimpel and IonE resident fellow David Tilman, a professor in the College of Biological Sciences, are co-investigators with agronomy and plant genetics faculty members Don Wyse and Craig Scheaffer on a $1 million U.S. Department of Agriculture grant led by agronomy and plant genetics associate professor member Gregg Johnson to assess whether growing biofuel plants might contribute to the biological control of soybean aphids. The researchers are evaluating the pest control benefits provided by insects that hang out in willow plantings adjacent to croplands, in prairie plantings adjacent to croplands and in settings in which both willow and prairie plants are planted near crops.

"We're going to look at the interface of those biofuel plantings and the surrounding productive agricultural land to see whether the biofuel plantings help with biological control," Heimpel says.

Besides carrying out specific research projects, Heimpel is using his IonE resident fellowship to spread the word about the environmental benefits of parasitoid alternatives to conventional chemical pest control.

"Not that many people know about biological control," he says, "so I can be an ambassador for that type of work."

APHIDS ARE NOTORIOUS competitors for human food supplies, cutting yields of crops by up to 50 percent in the case of bad infestations.

Closing the Loop on Electronic Waste

Best Buy's in-store drop-off program has made the consumer electronics retailer one of the largest e-waste collectors in the nation.

by DAN HAUGEN | photo by flickr.com/scoutingny

Outdated VHS players, computer monitors and cell phones spell out Best Buy's "e-cycle" message on a Times Square billboard.

MAKE NO MISTAKE: Best Buy likes to see customers lining up for that next new, must-have gadget. The consumer electronics retailer is in the business of helping people upgrade their technology, whether it's a mobile phone or a big-screen television.

For every new product, though, there's often an old one made obsolete: last year's iPhone, or a clunky analog TV set, or that computer your media collection outgrew. All of this stuff eventually starts to pile up in closets, landfills or incinerators.

It's an environmental hazard, and it's a customer hassle. That's why Best Buy is seeking to help close the loop on the millions of pounds of electronic waste its stores and customers generate each year.

Best Buy has rapidly become a national leader in e-waste recycling since launching an in-store drop-off program in February 2009. Customers at its U.S. stores can bring in just about any old electronics, regardless of where or when they were purchased, and Best Buy will make sure they get recycled responsibly. Last year, the company collected more than 75 million pounds of unwanted electronics.

That may sound like a lot—and it's no small feat for a program only in its second year. But it's still a molehill next to the mountain of e-waste we're collectively piling up. Consumer electronics make up one of the fastest-growing waste streams on the planet. The U.S. Environmental Protection Agency estimated that Americans alone jettisoned about 3.2 million tons of electronics in 2009, up from about 1.9 million in 2000. Of this, less than 20 percent was recycled.

That means the vast majority of e-waste is still winding up in landfills or incinerators, where the parts inside can release toxic materials, such as lead, mercury, cadmium and arsenic, into the environment. E-waste also contains a lot of useful commodities, such as glass, metal and plastic, which could be recycled instead of being buried or burned.

"There's a huge opportunity to bring more of this stuff back in," says Leo Raudys, Best Buy's senior director for environmental sustainability.

The retailer is extending the life of some products by collecting and reselling them through trade-in and buy-back programs. But its most visible and successful sustainability effort has been its in-store recycling program, which collects more than 300 pounds of e-waste per minute stores are open.

Raudys says they see it all, from old eight-track players and Miami Vice–style brick cell phones to busted printers and worn out video game controllers. The biggest categories by weight are TVs and computers. Other common items include cables and batteries. From the stores, e-waste is sent to one of the company's four recycling partners, where it's sorted, stripped, shredded, smashed and smelted into usable products.

Best Buy's goal is to recycle a billion pounds of consumer goods by 2014. It's an admirable target, but watchdog groups are more impressed with Best Buy's commitment to making sure what it collects is recycled responsibly.

The U.S. lacks significant federal regulation on electronics recycling, which allows companies that claim to be recyclers to get away with simply dumping material as cheaply as possible in poorer countries under the guise that it's being reused there. The Basel Action Network, a Seattle nonprofit that works on e-waste issues, estimates this is what happens with up to 80 percent of e-waste that's left with recyclers.

Lauren Roman, business director for Basel's e-Stewards recycler certification program, says she's "very pleased" with Best Buy's recycling efforts. Not only is the company making electronics recycling more accessible, it's also doing so in a way that's transparent and responsible. Best Buy annually audits its recyclers, and it won't work with a company if it or its partners export nonworking products to developing countries.

Best Buy's action is more notable because, in general, other members of the consumer electronics industry have done almost nothing to address the problem of e-waste except in states where they are legally required to do so, says Barbara Kyle, national coordinator for the Electronics TakeBack Coalition. Kyle also praised Best Buy for backing a federal e-waste bill that was expected to be reintroduced this year.

Best Buy's recycling program is already operating at slightly better than breakeven because the retailer shares a portion of the revenue its recyclers get from selling the separated materials. Raudys says the company is on pace to make its billion-pound goal by 2014 and is looking to expand the recycling program to its stores in Canada, China and the UK.

DAN HAUGEN is a Minneapolis-based freelance writer who covers business and technology. His work has been published in *Twin Cities Business*, *Delta Sky*, *Midwest Energy News* and other publications.

Power Play

by ERICA GIES

Utilities traditionally have generated power centrally, using coal-fired power plants, for example, and delivered it to consumers via transmission lines and distribution centers. But as renewable energy gains in the electricity mix, homeowners and businesses are increasingly seizing the opportunity to generate their own power or sell to the grid. Such distributed generation got a boost in June when Google announced it would invest $280 million in SolarCity, a company that installs residential solar panels. Most energy experts agree that distributed generation will be part of our energy future. But how big a part is a matter of some debate. To learn more, *Momentum* talked to Steven Weissman, who teaches energy and law at the University of California, Berkeley, and is advising the California governor's office on how to install 12,000 megawatts of distributed generation by 2020. Duke Energy spokesman Jason Walls works on distributed generation for the company, a major utility in the Southeast. »

" **THE CHALLENGES WE FACE** in trying to replace fossil fuel generation require an all-hands-on-deck approach. Distributed energy has an essential role in our future energy solutions.

Any kind of power generation requires land, but distributed generation can often piggyback on existing land uses. You don't have to take pristine desert land and cover it with solar cells; you can use space on existing roofs. There's great potential for developing distributed generation on public lands as well. We can use freeway rights of way or float solar cells on aqueducts and reservoirs.

If we rely on large central station solar and wind projects, we're going to need tremendous investment in new transmission facilities. It's very difficult to get permission to site transmission lines through our modern land-use pattern of suburban sprawl and dense urban areas. Where they are built, they often have to be underground, making them very expensive.

Also, transmission is inefficient. As energy travels down the lines, we lose a lot of power in the form of heat. The result is that you need to build more power plants to get the energy you need. Distributed generation overcomes this problem.

The most attractive distributed generation resource is solar photovoltaic because it's clean and quiet and unobtrusive. But variability is a challenge: The amount of energy generated can change minute to minute as clouds roll by. Utilities have to respond to these changes by, say, ramping up extra gas-fired power plants or by reducing demand, making grid management more complex and expensive.

However, distributed generation done right can address this problem better than central generation. If you've aggregated hundreds of megawatts via solar panels distributed across a region, then the total supply curve looks smoother as clouds move from one location to another. "

Steven Weissman
Associate Director
Center for Law, Energy and the Environment
UC Berkeley

" **DISTRIBUTED GENERATION** is not something that we proactively market. Rather, we see it as an opportunity for our customers if they are willing to assume that large capital investment. The payback period can be quite long, depending on the cost of the system.

We have roughly 400 customers in North Carolina and South Carolina who have a connection into our grid from self-owned generation on their property. The numbers are much lower in the other states in the Duke Energy service area.

Some have a net-metering relationship with us, in which they use the power they generate but buy extra power from us when necessary. Other customers sell all their generated power to us and then buy electricity like a regular customer. In both cases, we work with them to provide a safe interconnection, which is their financial responsibility.

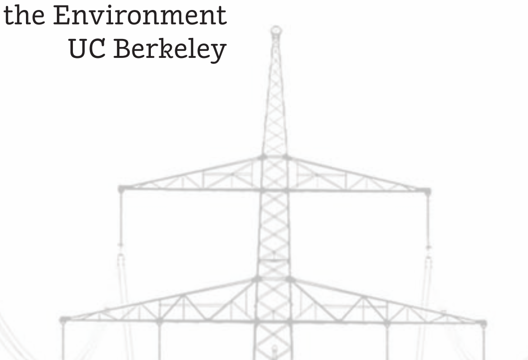
We agree to buy solar power from these customers in North Carolina at preset rates, which are then heavily subsidized by NC GreenPower.

While these customers do end up buying less electricity from us than regular customers, we don't see them as a threat to our business model. When you poll customers, they are most concerned about price and reliability. Solar systems are still expensive, and electricity rates in the Carolinas are about 30 percent below the national average. So as long as traditional generation remains reliable and that price remains low, we don't foresee distributed generation replacing it. In fact, our projections show demand for traditional base load, central generation continuing to grow well into the future.

While there are political pressures on coal-fired generation that could increase its price, nuclear is also a big part of our energy mix, and we see nuclear continuing to grow in importance to help keep prices low. We believe that traditionally generated electricity will continue to be competitive. "

Jason Walls
Communications Specialist
Duke Energy

ERICA GIES writes about energy, water and the environment for the *New York Times*, *International Herald Tribune*, *Forbes.com*, *Wired News* and other outlets. She is co-founder and editor of the website This Week in Earth (thisweekinearth.com).



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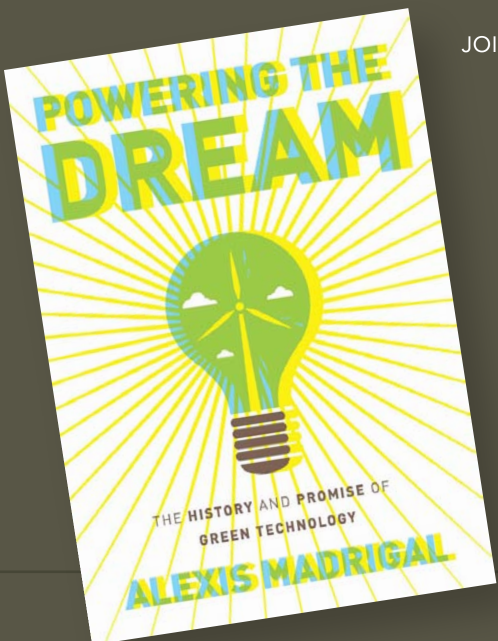

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