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From the Gene to the Globe

An interview with Julio Frenk

Julio Frenk, who became dean of the Harvard School of Public Health (HSPH) in January, has more hands-on experience in the field than most scholars. Frenk served as Minister of Health in Mexico from 2000 to 2006. In that role, he was distinctive for the opposite reason: he was the first minister with formal training in public health. Harvard Center for the Environment Director Dan Schrag talked with Frenk on May 4. Edited excerpts of their conversation follow:

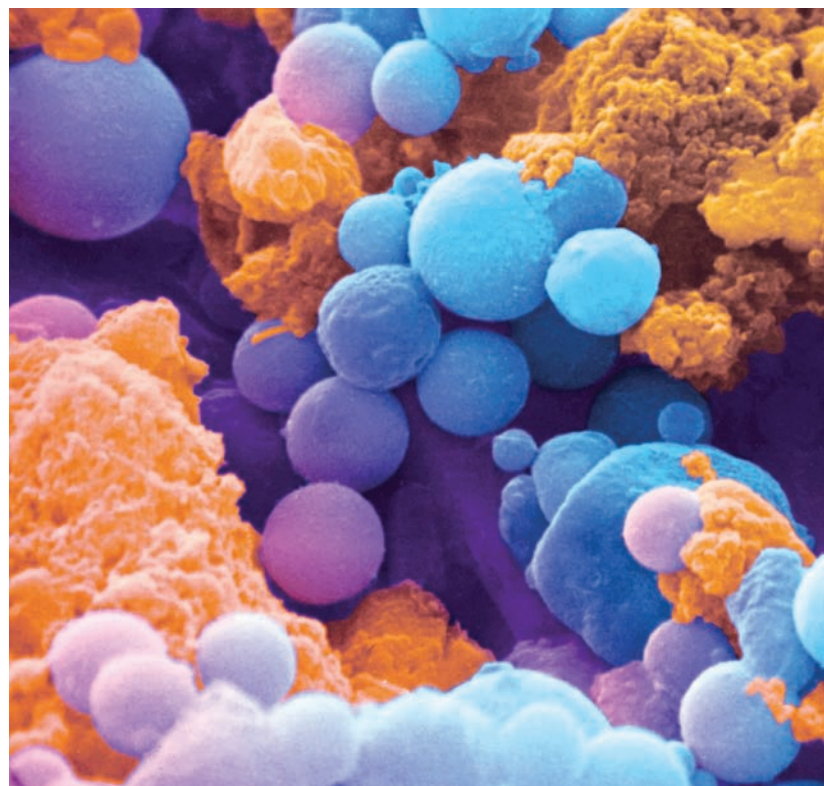
Schrag: What were your primary goals as minister of health?

Frenk: If I analyze the six years I was Minister, there were two fundamental agendas. One was to introduce universal health insurance. That's the part of my legacy that's best known because it was a highly successful program and it's right on track. There are thirty-five million people now covered out of the fifty million that have to be covered by 2010.

The second priority was the creation of a

whole new public health agency that did not exist before.

We called it the Federal Commission for Protection Against Health Risks. It's an elaborate name, but every word was carefully chosen. It was a commission rather than an individual...and that's based on the premise that collective decision-making tends to be better and much less susceptible to discretion, and therefore corruption.



Emissions from coal-fired power plants illustrate the intersection of health and environmental concerns: fine particles—such as the coal fly ash seen in the electron micro-graph image above—harm human health, while carbon dioxide emissions contribute to global warming.

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This agency, in a sense, was a little bit like the FDA, but with a substantial number of functions that, in the United States, would be carried out by either the Occupational Safety and Health Administration or by the Environmental Protection Agency, because it was explicitly mandated to determine standards for occupational and environmental exposures. And the structure was very carefully designed to be science-driven, with a topnotch scientific advisory committee chaired by none other than Mario Molina, the Nobel Prize Winner born in Mexico

Letter from the Director

Welcome to Environment @ Harvard, a new publication from the Harvard University Center for the Environment. With the hard work of our communications coordinator, Jenn Goodman, we've expanded our traditional newsletter to provide a sampling of the breadth of environmental research and activities across the University. I hope that Environment @ Harvard will give you a sense for the dynamic community of students, post-docs, and nearly 200 faculty associates that I've come to know during my five years as director of the Center.

In this inaugural issue, we include a mix of individual profiles and feature articles covering diverse topics

participants in our prestigious post-doctoral fellowship program.

Research is a big part of what we do at Harvard, but our biggest impact on the world is through our teaching. This point was made forcefully last fall during the visit of former Vice President Gore, who spoke to a crowd of well over 10,000 faculty, staff, and students on the occasion of the University's public commitment to its sustainability

give concentrators from departments throughout the college the chance to learn about the complex environmental challenges we face.

This past year has been a challenging one for the world and for Harvard as the global financial crisis has shaken our sense of security. We are extremely fortunate at the Center for the Environment to have the strong support of a group of loyal alumni who have provided the resources that allow us to continue to grow even as deep cuts are made around the University. Most

“Research is a big part of what we do at Harvard, but our biggest impact on the world is through our teaching...Vice President Gore’s own experience as a student here is one of the best examples of how Harvard can contribute to solving our current climate crisis.”

goal: a 30% reduction in greenhouse gas emissions by 2016. In his remarks, Gore not only praised the University for its moral leadership on this issue, but also reminded the crowd of Harvard's special role in addressing the climate challenge by educating future leaders.

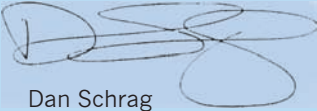
Vice President Gore's own experience as a student

here is one of the best examples of how Harvard can contribute to solving our current climate crisis. With that in mind, we recently launched a new interdisciplinary graduate program, the Graduate Consortium on Energy and Environment. Open to doctoral students from across the University, the program broadens the perspectives of graduate students from diverse fields while maintaining their individual specialized training in their home departments. It is the first program of its kind at the University and a model for interdisciplinary education at all levels. Over the next year, we will be developing similar opportunities for undergraduates through secondary fields designed to

of all, I want to thank Robert Ziff '88, along with his brothers Daniel and Dirk, for their extreme generosity, which has provided financial security to the Center for the next five years, and allowed me to create new programs including the new Graduate Consortium.

For those of you who are already part of our community of faculty, researchers, students, and alumni, I encourage you to take advantage of the services we offer, including the many speakers, workshops, and other events that our fantastic staff organize each week during the academic year. For those of you who have not yet engaged with the Center for the Environment but who share a curiosity and passion for understanding the grand environmental challenges we face, I urge you to explore this remarkable intellectual community by sending us an e-mail at huce@environment.harvard.edu and requesting to receive our announcements in the future.

With best wishes for a productive summer.



Dan Schrag



from green design and innovative energy technologies to designing the next international climate change agreement—and this represents only a fraction of the exciting work ongoing across the University. We lead with a discussion with Julio Frenk, our new Dean of the School of Public Health, as the first in a series of interviews with University leaders to learn about their goals to further research and teaching on environmental issues. Finally, we bring you up to date on the specific activities of the Center by reporting on the many faculty-led research workshops from the past academic year and our ongoing events series, and by introducing you to the newest Environmental Fellows,

[who helped uncover the damaging effects of chlorofluorocarbons in the atmosphere]. Mario chaired our scientific advisory committee. That made the environmental variable central to the whole work of the agency.

Schrag: Beyond traditional environmental health, what about this whole new class of environmental hazards coming from issues like climate change, that are potentially also going to threaten health, such as water resource availability; nutrition issues; and, especially for Mexico, the energy issue associated with declining oil production? That's going to affect the Mexican economy, but also health in Mexico, since there will be more pressure to use food crops for fuel.

Frenk: These environmental questions, to my mind, illustrate better than almost anything else the fact that we have moved into whole new domains that are much more complex than anything we faced in the past. We are in the midst of one of the most intense health transitions in the history of humankind.

The way to understand it is that developing countries are faced with a triple challenge. The first part is the backlog of the unfinished agenda. The second is a set of emerging issues. And the third challenge involves health threats emerging from globalization. Let me show how this relates to the environment.

In the first challenge—the backlog of problems—you still have the basic agenda represented by biological contamination of food and water. In large parts of the developing world, that is a major cause of diarrheal disease, common respiratory illnesses, and all manner of infectious diseases.

Without having completely solved the problems stemming from contamination of food and water, developing countries are now facing the new challenges posed by chemical pollution and air pollution. In addition, all of these countries are now exposed to threats that affect everyone in the world, most notably the

health consequences of global change, and phenomena such as the spread of global pandemics. Never before have health systems been subjected to such strain.

We used to live in a world that was generally dichotomous, accepting that, when it came to environmental risk factors, the poor countries would be subject to infections, malnutrition, and reproductive health problems caused primarily by biological contamination. In rich, industrialized countries, the problems centered mostly on non-communicable diseases and chemical pollutants.

Today, I would say practically every developing country has a mix of these two problems; and in addition, everyone in the world is exposed to this third burden: the health challenge emerging from the forces of globalization. Environmental questions are at the very heart of that and it makes the agenda very complicated.

For example, we have in a country like Mexico the longstanding problem of indoor air pollution because of the use of biomass for fuels --

Schrag: People burning charcoal in their homes?

Frenk: Right. The exposures are many times higher than the pollution from [power generating plants and transportation sources]. In rural areas of Mexico you still have the immediate problem of acute respiratory illness, not just in children, but also in women, who do most of the cooking. At the same time you are coping with the same pressures of climate change as everybody else.

So that illustrates this triple burden in a very clear way. Public health cannot focus only on one or the other of these three challenges. It has to address all three.



HOANG DINH NAM/AFP/GETTY IMAGES

A couple making coal bricks for cooking in a northern province of Vietnam. Indoor pollution from charcoal stoves, which are heavily used in most developing countries, is responsible for serious respiratory illnesses.

Schrag: How do you allocate finite resources among these different classes of problems?

Frenk: In what mixture, in what measure, that's the central policy question. But we're way past the simple old ways of a bipolar world when it comes to global health challenges.

Schrag: So now you've come to Harvard, to the ivory tower, although to a part of Harvard that is perhaps more involved in the real world than any other school. You have expertise at your fingertips: brilliant scholars who work on nutrition, on the environmental health risks associated with air pollution indoors and out, and who study epidemiology and infectious disease. Yet the tradition hasn't been of bringing these disciplines together.

Now that you are here, how do you actually craft new paradigms and new ways of thinking about health, global health, and environment? How do you actually implement strategies here at Harvard? In fairness, you and I have both been struggling with this.

Frenk: These are tough questions. I've been dean now for four months. I will say that, already, I can articulate not so much a vision as an ambition for this school.

My ambition is to make this the *first* school of public health of the twenty-first century. I use "first" in a double meaning: first in time, and first in quality.

Obviously, the question is, What is

Julio Frenk, dean of the Harvard School of Public Health.



KENT DAYTON

Graduate Consortium

Graduate Consortium Provides New Outlet for Energy Studies

Prior to the spring of 2009, Harvard graduate students who craved high-level engagement in the field of energy studies had few outlets. The Harvard Energy Journal Club, a student-run group that gathers to discuss peer-reviewed articles on energy-related subjects, was one; but the club meets only once a week, for just an hour. Additional opportunities for energy studies on campus were sorely needed. Now, students across the University have a solution: the Graduate Consortium on Energy and Environment.

Open to doctoral students from across the University whose research touches on energy and environmental issues, the Consortium was created to forge a community of young scholars—and a new generation of leaders—to grapple with the difficult energy challenges of the 21st Century. The program is designed to supplement the training students receive in their home schools and departments by exposing them to the broadly interconnected issues of energy and environment, while maintaining their focus in their primary discipline.

The core curriculum consists of three classes specifically developed for the program: Energy Technology, taught this spring by Michael Aziz of SEAS; Energy Policy, taught this spring by William Hogan of the Kennedy School; and Energy Consequences, which will be offered in the fall of 2009, taught by Dan Schrag of Earth and Planetary Sciences and the Center for the Environment. In addition to their regular coursework, Consortium

students are required to participate in a weekly seminar led by a rotating group of faculty from around the University. Seminar topics vary from week to week in order to expose students most broadly to the complex and multidisciplinary implications of energy and environmental challenges.

Spanning five graduate schools and 10 departments, the research interests of the 28 doctoral candidates who participated in the Consortium's inaugural semester this spring are as varied as the schools and departments from which they come. They run the gamut from the geopolitical impacts of transnational energy infrastructure (such as pipelines), to the human health consequences of energy technologies, to structural geology and the implications for carbon dioxide sequestration, as well as energy storage technologies.

One of the primary aims of the program is to facilitate stronger communication among students from these different fields. Rania Ghosn, third-year doctoral student at the Graduate School of Design, affirmed the success of this mission. "The Consortium has given me the opportunity to interact with students from the sciences and policy [areas] and broaden my interest in energy matters," she said. An added benefit of the multidisciplinary collaboration is that students gain a more nuanced understanding of the interconnections between energy, society, and environment within the larger context of their own research. As second-year doctoral student Emily Eames explained, "the Consortium has given me an opportunity to branch out from my research area, which I've found very stimulating and rewarding." Eames is a chemistry student researching multinuclear complexes for biomimetic small-molecule activation.

Third-year SEAS doctoral student Jason Rugolo, who opted to take both

of the core energy courses offered this spring, says he thoroughly enjoyed his first semester. "The systematic, insightful review by [Professor] Aziz" in the course on energy technology was, he says, "immeasurably useful." Rugolo found William Hogan's course on "the incredible complexity of energy policy" equally valuable. "I owe the understanding I have now of tough policy decisions to his ability to synthesize

and clarify difficult concepts in politics and economics."

For Eames and Liz Main, a fifth-year doctoral student in physics, the weekly reading seminars have been "the high point" of their affiliation with the Consortium. "I would happily participate in it for the rest of my time at Harvard if I could," said Eames. "It gives me the chance to think about an interesting new topic every week and discuss

Dan Schrag, Director of the Harvard University Center for the Environment, Sturgis Hooper professor of geology, and professor in the School of Engineering and Applied Sciences.

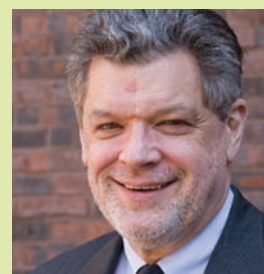
it with an expert." Main, whose research focus is atomic-resolution studies of high temperature superconductors, says that after every seminar she goes "back to lab bursting with ideas about the role of forests in the carbon cycle, whether polar sea ice has anything to do with

global warming, or whether coal plants are 'worth it' to society."

Consortium students are also eligible to apply for graduate fellowships and funding from the Center for the Environment to attend conferences or other professional activities during their time in the program.



Michael Aziz, Gordon McKay professor of materials science (School of Engineering and Applied Sciences).



William Hogan, Raymond Plank professor of global energy policy and research director, Harvard Electricity Policy Group (Harvard Kennedy School).

The Center gratefully acknowledges Robert Ziff '88, and brothers Dirk (MBA '93) and Daniel, for their support of the Graduate Consortium on Energy and Environment.

different about public health in the twenty-first century from, say, public health in the twentieth century? I think there are a number of issues, but I think one is especially relevant to this conversation.

Public health in the twenty-first century is fundamentally global. Global is not the opposite of domestic. The first big conceptual shift is to move away from the traditional divide between global, on the one hand, and domestic on the other. We've tended to use the phrase global health to signify foreign health; and we have a simple view, where basically problems and risks flow from the south to the north, and solutions flow from the north to the south. I think that is wrong.

Global is about the connections among every country and every population in the world, and risks flow not only from south to north—we tend to see infectious diseases traveling with people—risk factors also flow from north to south.

One example is differential standards for environmental safety and health. These allow the transfer of risks that are unacceptable in industrialized, developed, democratic societies to countries that have much weaker regulatory frameworks that will allow the import of toxic waste: the use of southern countries as dumpsites for the industrial wastes of the north.

Another example is tobacco. The two giants of tobacco production in the world are located in the United States and in the UK. So as their domestic anti-smoking policies become successful—tobacco control in the United States is one of the big success stories of public health and societal engagement—that, itself, creates an incentive for some of those companies to look for markets in countries where the regulatory focus is absent.

That's why I made it a priority, when I was Minister of Public Health in Mexico, to strengthen [the anti-smoking] program, because it's a very neglected side of the public health agenda. Because if you have an asymmetric world in terms of protection against risks, then you are creating incentives for this flow from north to south.

Conversely, policy solutions sometimes move from developing to developed countries, particularly through experiments in applications. In both cases, the big difference is that public health in the twenty-first century is global.

“My aspiration is to make global public health everybody's business at the University.”

Another major difference in twenty-first century public health is that it ought to be mostly about integration: reaching across disciplines, which we've been doing for many years, and reaching across levels of analysis. One of the great strengths of the Harvard School of Public Health is that it has the capability to take a problem and analyze it all the way from the gene to the globe. We have fantastic laboratory capacity and we have social scientists, policy scientists, and epidemiologists. If you look at an area like environmental health, we have people who are experts in doing very basic things—whether it be measurements of risks, or understanding the biological response to some exposures—all the way to epidemiologists who look at the distribution of those exposures in populations, and on to policy scientists who are trying to understand the policy process for setting exposure standards.

This is the strength of the School of Public Health. It's a problem-oriented school where you can take any health challenge and analyze it on all levels.

There is another kind of integration, which is what I call the integration between excellence and relevance: moving away from dichotomous thinking, in which it is one thing to do research and another separate process to translate that research into policy and practice. I think that what unites everyone at the School of Public Health is the fact that we all have a common product. The product is knowledge. This is what we produce and this is why we exist.

At this school, we do three things with such knowledge. We're engaged in its production, its reproduction, and its translation: the production of knowledge through research; the reproduction through higher education, where knowledge is reproduced in the minds of the next generation of leaders and scholars; and the translation into policy and practice, as well as translation to the general public through communication.

When you [recognize] that the unifying



Mothers and children walk on the shores of Lake Chad, which is heavily polluted and rapidly diminishing. The lake's toxicity has led to an increase of water borne disease infections and dwindling fish stocks.

element is knowledge, it no longer looks like separate activities. You may have specialized functions, but whether in the laboratory doing research; in the classroom teaching; writing a policy brief to influence the new Administration policies; or writing a press release to shape the public's perception, we're all handling the same product: knowledge. That's what binds us together.

I think that's the way to achieve the integration between excellence and relevance. Our knowledge has to be of the highest quality—that is, achieved through academic excellence—and it has to be extremely relevant to solving the problems of the world today. These are not separate objectives; they actually reinforce each other.

Schrag: I certainly agree with you. In other areas that's absolutely true. As you know, the Center for the Environment works hard to connect scholars across disciplines all over the University and encourage the best scholarship on environment. You're involved heavily in setting up a similar effort in the global health domain.

What can the rest of the University offer you: the Harvard Kennedy School,

the Business School, the School of Engineering, the Medical School and the Faculty of Arts and Sciences's economics and basic science departments?

Frenk: I always say that this is a great school and a great University. That's the rare combination. There are other good schools of public health in the United States, but they're not part of a great university. Conversely, there are great universities that do not have great schools of public health, or any school of public health. The particular mix that Harvard has is not common: a great school of public health at a great university. The corollary is that we have to mobilize all the intellectual capital of the University to

"We are in the midst of one of the most intense health transitions in the history of humankind."

take advantage of this privileged position.

Public health is not a discipline. It's a set of problems. When you mobilize talent across disciplines, that is when you achieve real progress. Global health issues are particularly amenable to this kind of University-wide participation. My aspiration is to make global health everybody's business at the University. In that way, we can bring the whole of Harvard's intellectual resources to bear on what is one of the most important topics of our time.

Schrag: Two of President Faust's principal priorities in science are, on the one hand, the environment and, on the other hand, global health. These are clearly two of the largest issues of our time. How do you think they could help bring the University together?

Frenk: I've watched with great admiration what is being done in the Harvard University Center for the Environment. I think in terms of a structural model—a governance model—that it offers very strong lessons

FACULTY PROFILE

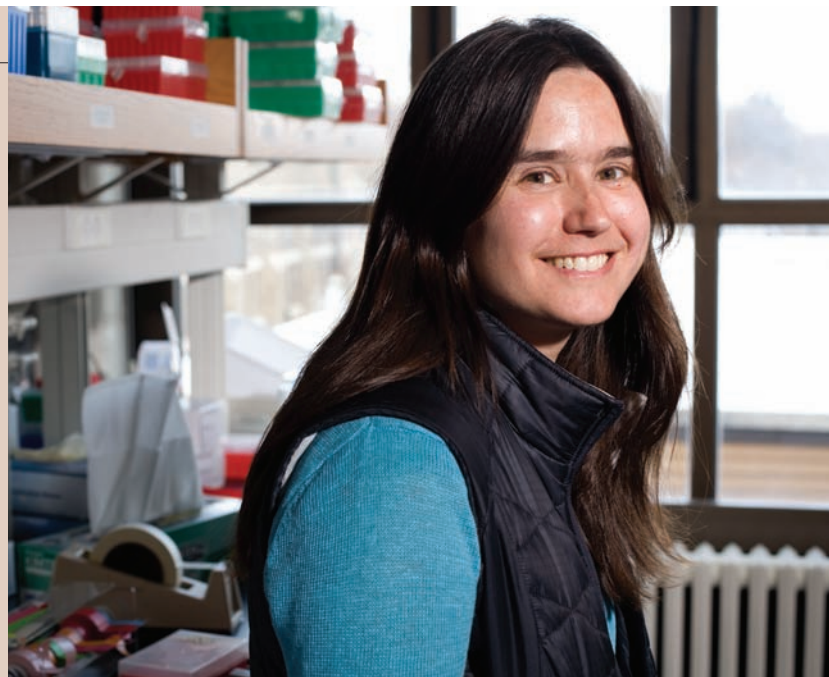
Anne Pringle

Anne Pringle is that rare scientist who doesn't speak like one, able to transition from the technical language of fungi—the kingdom at the heart of her academic work—to layman's terms with ease. To illustrate negative perceptions of fungi, for example, the assistant professor of organismic and evolutionary biology uses the example of a rotting wooden deck—an instance where fungi are viewed as a cursed affliction. "But," she says, "in our world, it's a problem to get rid of standing, dead materials." That's where fungi come in, forcing you to treat your deck, yes, but also breaking down some less desirable things. "If there weren't any fungi, dog poop would last forever," she says. Plus, beer and wine are fermented with fungus; detergent uses fungal enzymes to make the clothes cleaner. "Fungi have all sorts of hidden roles in our world."

Pringle is adept at relating her academic interests to everyday life, probably because she has to do a good deal of explaining. "There are a lot of people who don't have a good idea of what this kingdom is," says Pringle. "And I think that's because most [students] never have an opportunity to take a mycology class or learn about this particular group of organisms." On top of that, fungi often have indirect effects on the population—killing crops and driving up wheat prices, for instance—as opposed

to something like West Nile virus, which affects people directly and is therefore more prone to make headlines.

It was this uncharted, enigmatic quality that first attracted Pringle to the study of fungi during her graduate work at Duke. "It was a bit of a black box," she says. That's still true of the work she does today; her two current research projects are filled with unknowns and unanswered questions. The first is an investigation into the spread of a mysterious poisonous mushroom in California, responsible for at least one recent fatality. Pringle is also in the midst of a long-term survey into the life-cycle and growth rates of lichen, using populations found on tombstones at a cemetery in Petersham, Mass. "There's been no long-term survey of fungal populations, so we have a poor sense of what a fungal demography would look like," she says. For different species of birds, science may have a good idea of whether they will live seven or seventy years. "But for most species of fungi, we



have no clue whether it will subsist for one or five or 100 seasons."

A greater understanding of fungi, Pringle says, is crucial to helping protect the environment. Fungal enzymes are critical in breaking down plant materials to create biofuels. They also provide access to nutrients for trees, which in turn absorb and store carbon dioxide in a process called carbon sequestration. "If you're trying to think about sequestering carbon, you have to think about the fungi that are in a symbiotic relationship with the roots of plants, helping them survive and grow," she says. It's critically important work that—as Pringle knows well—sometimes goes unnoticed.

—Dan Morrell

for what the University could do in global health. I would hope to establish a similar initiative—one as successful as the one you’ve built centered on the environment—so that our two groups will continue the very deep communication they are already having as part of the terrific group on global health and environmental issues.

I think it’s a very exciting conception. And I think President Faust was right. These are probably the two best topics in science today for uniting multiple groups from across the University. I would like to see people within disciplinary approaches adopt global health as an arena for advancing [their own work]. People who are interested in development studies could see health as a way of testing their theories; people who are interested in the role of diplomacy, at the Kennedy School, for example, could see global health as an arena in which to advance the study of international relations; people who are interested in global trade could explore health as a focal point for questions around trade; and scientists who are interested in the spread of risks across borders [could study this through the lens of global health]. Public health offers a whole collection of problems around which these disciplines can advance their own fields of interest.

Certainly, we are seeing that undergraduate students, particularly, are enormously interested in global health. I have the impression there is a new idealism among young people in American universities. They see that global health [and energy and the environment] are offering new challenges.

How we offer those opportunities not just to graduate students, which we already do at the School of Public Health, but now increasingly to the undergraduates, is a very exciting question.

Schrag: One of the opportunities on which the Center for the Environment is hoping to work with you, is finding ways of creating financial incentives that will encourage faculty in public health to teach undergraduates, so that they can learn the problem-solving skills your school requires, developing expertise that is often quite different from that learned in the arts and sciences.

Frenk: I think that’s the intersection. We must take these topics that are inherently

integrative, like energy and environment, and global health, and mobilize the wealth of interest. I would love to see a handshake between those communities

that are discipline-oriented and those that are problem-oriented. That’s the handshake that a place like Harvard can stimulate.

FACULTY PROFILE

Harvard Goes to Washington

The historic election of President Obama created new possibilities for substantial action on energy-environment issues. The Center is proud to recognize the following members of the HUCE faculty community who have joined the new administration to work on environment-related issues.

John Holdren,
Assistant to the President for Science and Technology (President’s science advisor)

Holdren, a University leader across a broad spectrum of energy-related policy and technology research areas, has taken leave from the Harvard Kennedy School to serve as science advisor to President Obama. In a *Science* magazine editorial from May 2009, Holdren laid out the top priorities and practical challenges for the Obama administration in the next four years: giving science and technology a central role in job creation and economic recovery; reducing energy imports and climate change risks; advancing biomedical science and information technology to improve Americans’ quality of life; and ensuring national defense through policies of arms control and nonproliferation.

Jody Freeman, *Counselor for Energy and Climate Change in the White House; Senior Advisor to Carol Browner*
Freeman is the founding director of Harvard Law School’s Environmental



ROSE LINCOLN/HARVARD NEWS OFFICE

Law Program, where she devoted her attention primarily to issues of carbon sequestration and climate change. At the White House, she is charged with managing environmental regulation and legislation as the federal government works to revise its climate change policy.

Lawrence H. Summers, *Director of the White House’s National Economic Council*
The appointment of Lawrence Summers to the National Economic Council came as no surprise to his colleagues and peers at the University. Summers played an instrumental role in setting the Center on its course.

He actively supported environmental research initiatives around the University and remained highly engaged in the Center’s work, both during and after his tenure as President. Now in Washington, he remains interested in climate and energy issues, particularly in an economic context.

Ashton Carter, *Under Secretary of Defense for Acquisition, Technology and Logistics*

Ashton Carter has taken leave from the Kennedy School to serve a presidential administration for the second time in his career. From 1993-1996, Carter served as Assistant Secretary for International Security Policy under former President Bill Clinton. He now lends his extensive expertise on nuclear energy to the Department of Defense.

Dan Schrag, *Advisor, Presidential Council of Advisors on Science and Technology*

HUCE director Dan Schrag joins a distinguished cast of scientists who will advise President Barack Obama on policy decisions concerning energy, climate change, and other scientific issues. The council is co-chaired by John Holdren.



LEAH FASTEN

A Future for Biofuels

Can the luster be restored?
by Doug Struck



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The dream of producing ethanol from corn, when it proved an empty promise, made it rough for all biofuels. The allure of running our cars on the golden grain more plentiful in America than anywhere else was too much to resist. Corn-based ethanol offered a promise of an environmentally benign alternative to gasoline, and a way to thumb our noses at Mideast oil sheiks, all while adding another medal to the chests of our venerated farmers.

President Bush lauded corn ethanol. State legislatures embraced it. Gasoline stations put in special pumps, and farmers

rushed to plant more corn. In 2007, Congress ordered a stunning fivefold increase in production of biofuels within 15 years, and mandated that at least 40 percent be made out of corn.

Then the tarnish began to show. It turns out corn ethanol saves little energy when all the farming activity is counted. Using corn for fuel was blamed for boosting food prices globally, creating sticker shock at the supermarket and food riots among the poor. And the net effect of plowing up vacant prairies or forests to plant corn may be even worse for the climate. Corn ethanol began to look more like a fat and flawed windfall for agribusiness than anything else.

“There was a whole lot of hype that gasoline [would] grow on trees and this would be essentially free energy,” said Michele Holbrook, a biology professor at Harvard. “We are starting to look at it more soberly now.”

So the tweaking of the idea began. Instead of existing cornfields, perhaps it could be grown on spare property. Instead of corn, ethanol could be made out of wood chips or weeds—or perhaps, algae?

A handful of researchers at Harvard, scattered across a range of departments, are trying to determine whether any of these solutions are plausible. They are searching to determine if biofuels are a good idea gone bad, or whether they can

be a solution to our energy problem and beneficial for humanity.

The researchers include geneticists working on new ways to make the fuels, economists who see biofuels as hope for poor countries, policy analysts and biologists, all exploring whether we may yet turn to living nature for fuel. None claims to have found the perfect path yet. But their work reflects an optimism that there are new technologies to be developed, new policies to be tried, new science to be created that might yet overcome the obstacles.

The obstacles are daunting. The numbers tell the dilemma:

—Half of the nation's current corn crop would be needed to produce the 15 billion gallons of corn ethanol required by Congress for 2022, and that will replace just one-tenth of our gasoline.

—Taking food crops from fields to use for fuel will increase global food shortages, adding to the 850 million undernourished people in the world.

—If we used every bit of the estimated 1.3 billion tons of organic material in this country, including every available field, shrub, wood chip and municipal waste, we still would meet less than 30 percent of our daily fuel appetite with biofuels made by enzymes or chemicals.

—New biofuel schemes would involve remaking a big part of a \$1.5 trillion oil infrastructure by requiring thousands of new production plants, new delivery systems, or new adaptable cars.

With roadblocks like that, are biofuels destined for the trash-heap of misguided ideas? Already, Europe has started to pull back subsidies and tax breaks adopted just a year or two earlier, and is desperately trying to regulate ethanol's impact on food prices and toll on the land. Texas demanded—but did not get—exemption from the federal mandates to use ethanol. Environmental groups, once upbeat about corn ethanol, now put it on their list of villains. In March 2008, *Time* magazine delivered the modern-day coup de grace, a cover story headlined, "The Clean Energy Myth."

The inspiration for ethanol, and still the chief exhibit offered in its defense, is Brazil. Following the oil shock of 1972, Brazil's military government decided the country's sugar cane industry could help alleviate the cost of importing oil. It began building an ethanol industry that required

new cars to run on ethanol mix and mandated that gas stations sell it. Twenty-five percent of the fuel sold at all Brazilian gas stations comes from crops grown in the country, processed at more than 400 ethanol factories. Brazil has declared itself energy independent, and is the world's largest exporter of ethanol, with plans to aggressively expand foreign sales.

But Brazil's ethanol is made from sugar cane, and corn is not an equal substitute. Cane is about twice as efficient as corn in converting sunlight to mass. And cane requires a lot less effort to grow, at least in the tropics like Brazil. With abundant sunshine, ample rain, and minimal fertilization, cane sprouts like the natural grass that it is.

Corn, by comparison, requires large amounts of nitrogen added to the soil, regular irrigation in some parts of the country, and mechanical tending to prepare the land, plant the crop, harvest, and process it. When all of the fossil fuel used in production is counted, sugar cane is roughly eight times more energy efficient than corn in producing ethanol.

But cane does not readily grow outside of the tropics. In the United States it is suitable only in Hawaii, south Florida, and parts of Louisiana and Texas. So green advocates have looked to biologists for help. Perhaps crops can be developed to improve their biofuel potential, just as researchers dramatically improved agricultural yield in the "Green Revolution" in food crops.

Holbrook, who runs a lab in Harvard's Department of Organismic and Evolutionary Biology, cautions not to expect dramatic results. The Green Revolution tripled crop yields by increasing inputs of nitrogen and selecting for plants that convert a greater proportion of their photosynthesis into seeds, she says. It did not, however, alter the basic efficiency with which plants convert sunlight into biomass. A dramatic advance in ethanol production would require zippiest photosynthesis to

produce more energy, or re-engineering the woody walls of plants to make it easier to break into the structure to steal the sugars. Both require improving on processes that nature has honed over eons of evolution—not a good bet, she says.

A plant's photosynthetic process is complex. It is joined to the plant's survival and structure, and has been optimized by evolution. Even if we could improve on that, Holbrook notes, engineering the perfect biofuel plant would create other problems.

"Let's imagine we could re-engineer corn to make perfect stalks of cellulose or to become a perfect starch machine," she says. "We would still have to grow a lot of this

crop to produce large amounts of fuel." Much of the most productive land is already used for food production. It is hard to see how we could produce large amounts of biofuels without competing with agriculture, she says.

Enter the next great idea for biofuel production: instead of trying to ferment just the sugars of corn or cane into alcohol, ethanol could be made from the cellulose of any organic matter—from the leftover stalks of corn after harvest, to

grasses or wood chips or the rakings from lawns and tree trimmings.

This technique uses acid or enzymes to break the cellulose away from the lignin that gives the plant its structure, after which the cellulose can be fermented to obtain the energy. Cows and sheep do this in their stomachs naturally.

Some environmental groups, such as the Natural Resources Defense Council, believe this is the answer for future biofuels. They say corn-based ethanol is only the flawed first version, and that cellulosic ethanol will end the competition of food with fuel, and spread the organic sources of ethanol across a much larger and more diverse landscape, making it—in theory—easier on the land.

They envision vast fields of switchgrass, a tall prairie grass, grown without water on

Half of the nation's current corn crop would be needed to produce the 15 billion gallons of corn ethanol required by Congress for 2022, and that will replace just one-tenth of our gasoline.

vacant land, and harvested for fuel. They note that the lignin plant structure that is left after cellulose and carbohydrates are taken can be used to help fuel the conversion process, giving the whole operation a much better greenhouse-gas advantage than simply fermenting corn.

"If biofuels are done right, we could soon be filling our tanks with clean, renewable, homegrown energy," the NRDC says in its brief touting cellulosic ethanol. "It may sound too good to be true, but it's not. Scientists, farmers and auto experts agree that, if they're grown and produced properly, biofuels can help free America from our oil dependence."

Congress has written this unproven cellulosic ethanol technology into the law with the same vigor that it embraced corn ethanol. In the 2007 Energy Independence and Security Act, Congress said that of the 36 billion gallons of biofuel it wants produced by 2022, 15 billion gallons must come from corn-based ethanol and at least 16 billion gallons from cellulosic biofuels.

But cellulosic ethanol has problems, as well. Ethanol—no matter how it is made—has an unfortunate affinity for water, which accumulates in pipelines, so ethanol cannot be shipped in the existing fuel infrastructure. It requires a whole new delivery system. It also has relatively low energy density, meaning it cannot realistically power airplanes, ships, or even trucks, which would have to carry too much fuel to move their mass.

Biodiesel, which in this country is made primarily from soybeans, provides less

than 1 percent of the fuel for diesel engines domestically. Significant expansion of soy-based cellulosic biofuel production runs into the same land and food conflicts as corn.

And the vast vacant lands needed to grow some sort of plants to turn into cellulosic ethanol are not so handy. Well-nourished and well-watered fields that could grow all the switchgrass needed are likely to be the most productive fields that farmers already use. Looking at the congressional requirements, farmers may end up simply making the logical decision to plant more corn for fuel on their productive fields, say three researchers at Iowa State.

The rules intended to avoid a food-vs.-fuel conflict "may actually exacerbate the situation," wrote Dermot Hayes and Bruce Babcock, economics professors at Iowa State University, and Mindy Baker, graduate student, in a 2008 study on the economic choices facing farmers. "Cellulosic ethanol is more expensive to produce (than corn ethanol), and switchgrass-based ethanol is more land intensive," they concluded. Without higher subsidies, "rational farmers will not grow switchgrass or soybeans for biofuel production, and rational investors will not build these plants."

"There was a whole lot of hype that gasoline [would] grow on trees and this would be essentially free energy. We are starting to look at it more soberly now."

Could bugs help? Researchers at Harvard are collaborating with others across the country to create microbes that process organic matter directly into ethanol or other biofuels. A leader in this is George Church, a professor of genetics at Harvard Medical School, whose development of fast, automated methods

of genome sequencing and synthesis has helped bring down costs by 10,000-fold.

He is using the same computer-assisted techniques at the medical school's soaring glass-and-chrome New Research Building to splice genes into bacteria to produce new chemicals including biofuels. Church's system takes DNA from other organisms, transplanting or optimizing not just one gene at a time, but whole metabolic systems.

LS9, a company founded by Church, is headquartered near San Francisco and makes what it calls "designer biofuels" by genetically engineering the *E. coli* bacteria to feed on biomass and excrete fatty-acid-based hydrocarbons. The genetic alterations improve the efficiency of the natural process that the bacteria use to store excess energy, which causes them to release the stored energy as a liquid.

LS9 mixes the engineered bacteria in vats of water to ferment sugarcane, and the company says it can siphon the resulting biofuel off the top and put it straight into diesel gas tanks. LS9 says sugar cane is only one feedstock; the *E. coli* will feed off a wide variety of biomass. The advantage, they say, is that such biofuels do not need a new pipeline system or engines and can be produced from almost any biomass.

SunEthanol, a spin-off originating at the University of Massachusetts Amherst, is using a natural bacteria, with an alias the company guardedly calls the "Q Microbe,"



Noel Michele Holbrook, Charles Bullard professor of forestry and professor of biology, stands among plants in the Harvard greenhouse. Holbrook believes engineering crops to improve their photosynthetic process—and thus their biofuels potential—is "not a good bet."

to get higher yields of ethanol from diverse biomass to power gasoline cars.

These biological solutions have advantages on the energy balance sheet. But they still would require a huge source of organic material, whether it is sugar cane or grass or waste wood, to eat.

Church believes algae can be designed to skip the need for biomass. At another company he helped start, Joule Biosciences, Church's colleagues are exploring the abilities of genetically modified algae to produce crude oil that can be refined into any biofuel product. Other companies are also charging down the algae path: Greenfuel Technology in Cambridge has built experimental farms with algae that feed off industrial exhaust and emit biofuels; Sapphire Energy in San Diego says its algae will live in wastewater or saltwater, so freshwater supplies are not tapped.

Church asserts that the science puzzle of how to create biofuels using microbes is largely finished; the challenges are economic and technical in making it work on a large scale.

"Engineering microbes to make the hydrocarbons you want is a solved problem," he says. Microbes are efficient processors, and "all you need to do is skim off the fuel," he says. "I think we know enough about metabolism that it can be handled by a good engineering team."

But the manufacturing is far from solved. The large-scale use of organisms like algae would require large-scale living space, and gives rise to many complications. Algae, for example, can be finicky about temperature. They require water. And they can produce toxins.

Creating an infrastructure of vast ponds or vats to feed and nurture the microbes—whether algae, *E. coli*, or some other organism—from which the output could be harvested would be expensive. We already have some experience in aqua-farming. Algae are being grown in aqua-culture farms as a food. But the cost is many times that needed to make it an economic source for fuel.

Pamela Silver, a professor of systems biology at Harvard Medical School, thinks we ought to try a different tack. "Forget about biomass. Think about sunlight," she says. She wants to create a creature that produces fuels directly from sunlight. She and her students are closing in on what she calls a "Personalized Energy Program,"



*George Church, professor of genetics and director of the Center for Computational Genetics, Harvard Medical School. One of several research avenues Church is pursuing involves the genetic modification of *E. coli* bacteria for the creation of "designer biofuels." The altered strain is designed to feed on biomass (like sugarcane) and release its stored energy in liquid form, resulting in biofuels that are ready for the gas tank.*

in which one could grow cells in their backyard that would produce hydrogen to make power.

"We could reprogram microbes to go from sunlight to hydrogen via photosynthesis." Ultimately, such reprogramming might yield products other than hydrogen, such as organic plastic, rubber, or some kinds of drugs, she says.

Silver got her first whiff of the potential of biofuels years ago when she was invited to Brazil to teach researchers how to work with the proteins of yeast. When she stepped out of her hotel in Sao Paulo, "I said, 'what's that smell?' It was the sweet smell from the burning of ethanol in cars."

Silver is a proponent of synthetic biology. This new branch of research attempts to use the natural building blocks of life as modular units that can be rearranged to dictate the outcome. It could, for example, use the predictable responses of cells to build an organic computer. It is a line of research that has generated moral questions over the human creation of new organisms.

Researchers have already proven that cells can remember past signals, and Silver's

lab is expanding on that to try to create predictable mechanisms from the cells—in effect, machines. But she says her students have bigger goals.

"One day we were sitting around, and said, okay, this is well and good, but what can we do to change the world? We said, 'Energy.'"

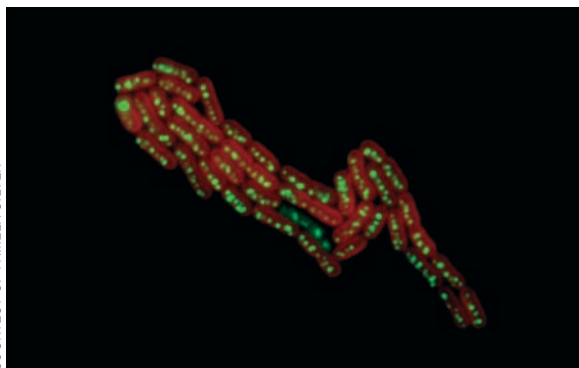
Their approach is to splice DNA and synthesize the genetic makeup of bacteria to produce a new organism that always does what researchers want—a predictability absent in random natural processes. The process of making a fuel that way involves constructing a complex organism that can process energy through intermediates to a very long molecule of fuel, what Silver and others have called "the ultimate metabolic engineering problem."

Such cells would require few inputs other than sunlight and are self-replicating, she says, so producing fuel from them would not require growing, harvesting, or moving vast amounts of biomass.

The prospects have led to a high-stakes rush by researchers, watched intently by big corporations. Private entrepreneur Craig Venter, who was instrumental in mapping the human genome, is working to synthesize a new microbial genome and insert it into a cell so that it survives and replicates as a new species, to be named "Synthia." Venter has been scouring the globe for rare microbes with unusual metabolic pathways he might replicate in Synthia. BP is helping bankroll Venter in his quest for a man-made superbug; Chevron is working with a synthetic biology company to try to make biodiesel



COURTESY OF PAMELA SILVER



Pamela Silver, professor of systems biology and director of the systems biology graduate program, Harvard Medical School, is attempting to engineer cyanobacteria (above) that will use only light to self-replicate. Silver sees a sunny future for this method of biofuels production, envisioning her lab's success within the year. "Forget about biomass," she says. "Think about sunlight."

from synthetically altered algae; and DuPont already produces a commercial organic plastic using a synthetic organism.

Silver envisions success in her lab in producing biofuels within a year, and perhaps hydrogen after that. But the application of that research success is another matter; it would involve taking the lab results from the size of a petri dish to a much larger scale. Even backyard power plants of synthetic organisms would require facilities and attention. On a commercial scale, these ideas would involve large—and expensive—structures to house and grow the bacteria to harvest the fuel. And would the cells efficiently produce enough hydrogen, say, to make it a profitable effort?

"I work on the biology part," Silver demurs. "It's up to government and industry to decide how to go from there."

Another possibility is to use our industrial muscle in a new way to obtain energy from organic material, by adapting an old idea. In the 1920s, German researchers Franz Fischer and Hans Tropsch found a way to create diesel fuel from coal, which Germany had in abundance. The Fischer-Tropsch method involves heating coal or natural gas with limited oxygen at high temperatures to turn it into hydrogen and carbon monoxide gases, called syngas. The syngas is then passed over a catalyst to turn it into a wax or liquid of long-chain

during World War II—producing 124,000 barrels a day—that the production plants became targets of Allied bombing raids. South Africa used the process to create fuel during the economic embargo over its apartheid policies before 1993, and continues to make fuel and chemicals with the process today.

But coal or natural gas are not the only possible inputs. Dan Schrag, professor of earth and planetary sciences and the director of HUCE, envisions gasifying biomass—plants, leaves, wood, municipal waste, grasses, pulp plant leftovers, or practically any organic product—to produce biofuels with the Fischer-Tropsch process. The fuels would be interchangeable with diesels or jet fuel and gasoline that we use

now. The fuel burned would recycle the carbon between the atmosphere and the plants used to make the fuel, and therefore would be carbon-neutral.

The amount of wood and plants needed to produce enough liquid fuel to make even a modest dent in our transportation uses would still be enormous, Schrag acknowledges. He proposes mixing the biofuels with coal,

which would make the combustion more efficient and would multiply the output of biofuel. The greatly increased output would go a long way toward overcoming the limits of the supply of biomass, which otherwise would constrain biofuels to a small fraction of our transportation needs. The carbon emissions from the coal would be captured and sequestered, Schrag

proposes.

The idea has the advantage of using a proven technology to produce biofuel substitutes that could seamlessly feed into our existing transportation system. It could use a diversity of feedstock, eliminating the need to plant millions of acres with a single crop. And it uses more of the plant than fermenting starches or extracting cellulose.

But it would require permanent sequestration of carbon dioxide, and the economic and safety questions of such large-scale sequestration remain unresolved.

And, as with many of the proposed schemes of producing biofuels, the cost of building huge gasification plants would be enormous. The higher productivity of

“What is scary about ethanol support was the government saying, here is the winner, rather than letting the facts on the ground—all of them—dictate. The worst case would be assuming that bio-fuels will solve all of our fuel demands so we don’t have the will to do anything else.”

the process, Schrag asserts, would justify the capital costs.

Whether we ferment it, feed it to microbes, or cook it, the production of biofuels from biomass will require a vast supply of organic stuff. If the “stuff” is crops—whether corn or sugarcane or prairie grass—it takes up land. Processes that use municipal waste products or scraps from paper pulp plants would cut down on the land needed, but those sources alone are not going to provide enough mass to significantly reduce our gas and diesel fuel appetite of 175 billion gallons a year.

So another question lies in quiet ambush: even if we settle on how we make these fuels, can we grow or find enough biomass to make it worthwhile?

A 2005 study by the departments of Energy and Agriculture estimated that farming leftovers, logging waste, pulp processing waste, and the harvest from 55 million acres of new crops would produce about 1.3 billion tons of biomass a year. If we used every bit of that to convert to biofuels under current techniques, it would meet only about 20 to 30 percent of our transportation fuels demands.

“The question is, is there sufficient biomass to meet the goals,” asks Henry Lee, director of the Environment and Natural Resources Program at the Harvard Kennedy School. Lee is looking at some of the implications of our quick infatuation with ethanol, and at the longer prospect for biofuels from other crops.

His research leads quickly to issues of land use, and to the conflict between growing food and growing fuel. When farmers started sending their corn to ethanol plants, an explosion of prices followed. That buoyed farmers and hurt consumers. Corn ethanol production was blamed for food riots in Egypt, higher tortilla prices in Mexico, and increasing undernourishment in Africa.

It is unclear just how much to blame ethanol, Lee says. The ‘price shock’ that hit food prices was the end result of several trends, according to Lee: ballooning oil prices that increased the cost of production, a rising world population with more affluent people demanding more meat, and a dwindling corn harvest surplus in the United States.

Estimates of how much ethanol production contributed to the rise in food prices range wildly, from 3 percent to 65

percent, according to Lee. But he says there is little doubt that using corn for fuel does offend sensibilities at a time when almost 3 billion people live on less than \$2 per day and must struggle for food.

“There’s a real tension in the developing world between food and fuel,” Lee says. “If you begin to shift farmland from food production to fuel production, that’s a real problem.”

The conventional answer is to use cellulosic biofuels, to grow the organic material such as switchgrass, or the towering tropical grass miscanthus, on “idle” lands not being used for food crops. That ignores laws of economics, though: farmers will use their land to grow whatever brings them the most money, and the land that is most productive for food usually will be most productive for growing biomass.

To some extent, advocates of biofuels depend on the market process to solve the food vs. fuel debate. If food prices rise, they argue, farmers will put more land into production. That will act to both moderate prices and provide farmers more income, they say.

But the experience of palm oil farming is exposing the danger of relying only on

market mechanisms, which have no place on ledgers for social or biological values. Palm trees are incredibly productive, relinquishing about 35 times more oil per acre than corn. Palm oil is widely used in food processing, sold for cooking, and in making such products as soap. But its value as a source of biofuel has sent its price rocketing. In a stunningly short time, Southeastern Asian tropical forests are being devastated as poor farmers carve

A section of Borneo rainforest that has been clearcut for use as a palm oil plantation. The value of palm oil as a source of biofuels has soared, leaving policy makers to decide whether the economic rewards justify the environmental risks.



FRANS LANTING/CORBIS

Henry Lee, director of the Environment and Natural Resources Program at the Harvard Kennedy School. Lee questions whether the world has the capacity to grow sufficient biomass to make ethanol, or other biofuels, a viable solution to the world’s energy problems.



palm farms out of forestland.

The United Nations said the blossoming of palm oil plantations “is now the primary cause of permanent rainforest loss” in Indonesia and Malaysia, and will wipe out Indonesia’s forests in 20 years. Animal-rights groups say the burning of peat forests already is threatening hundreds of species from orangutans to the world’s largest butterfly.

“Some have an idea that cellulosic ethanol is going to solve all the problems, and it’s not going to have environmental implications. They have not examined it very rigorously,” says Lee.

Cellulosic biofuel advocates reply that there must be new rules; governments must restrict planting for fuel only to

that they have long fought to protect.

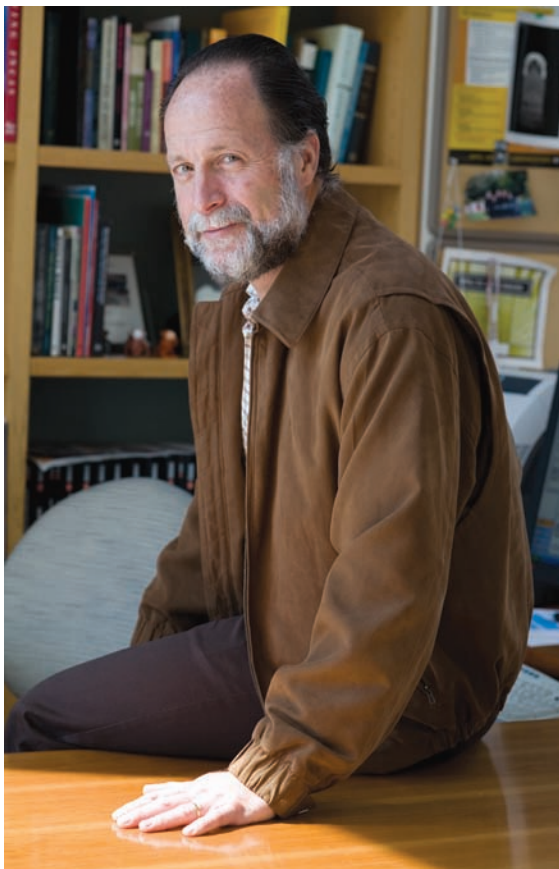
The “unused land” solution also ignores the environmental value of unplowed land containing natural vegetation. Whether it is forests or scrub, that land is storing carbon; more than three times as much carbon is in land as is in air. Cutting the forests or plowing the fields releases that carbon through burning or decomposition. Researchers are just beginning to try to calculate how much, and the view is not pretty.

University of Minnesota ecologist David Tilman concluded that clearing land for corn or cane creates what he called a “biofuel carbon debt” many times worse than using fossil fuels. Timothy D. Searchinger, of the

In Europe, those concerns have led to a call for “certification” of the sustainability of biofuels. European lawmakers, who in 2007 agreed on a 10 percent biofuel requirement by 2020, are considering restricting biofuels to those that meet standards on a checklist that includes carbon balance, food prices, child labor, economic development, forest preservation, and a myriad of other social goals.

But it quickly becomes too complex to predict and too hard to juggle all of the consequences, Henry Lee argues. “Don’t try to solve all the world’s ills on the back of biofuels,” he urges. “You can’t do everything.”

And don’t do it on the back of



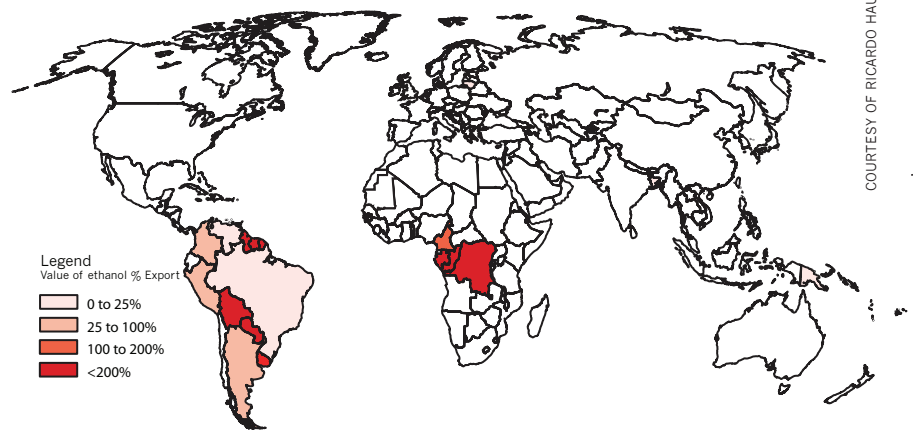
Ricardo Hausmann, professor of the practice of economic development and director, Center for International Development, Harvard Kennedy School. Hausmann sees tremendous potential for crop-based biofuels to transform the economies of developing nations.

abandoned cropland or vacant prairies. Environmental organizations are just now realizing that fully exploiting cellulosic biofuels in this country would mean raiding conservation reserves and land

over a 30-year span, biofuels end up contributing twice as much carbon dioxide to the air as that amount of gasoline would, considering all the global effects.

Replacing even scrubland with crops hastens the decline of biodiversity, already a serious worry for biologists. And without enough natural rainfall, any biofuel crop would deplete underground water aquifers, which already are dropping globally, largely because of agricultural irrigation.

Potential Impact of New Biofuels Industry if Developed
(as % of current exports)



COURTESY OF RICARDO HAUSMANN

Woodrow Wilson School of Public and International Affairs and Princeton Environmental Institute, used a worldwide agriculture model to estimate emissions, and found that plowing new land for corn ethanol nearly doubles greenhouse gas emissions and increases greenhouse gases for 167 years. He concluded that

poor nations, says economist Ricardo Hausmann, Lee’s colleague at the Kennedy School, a former planning minister of Venezuela and chief economist at the Inter-American Development Bank.

Hausmann looks at biofuels and sees coffee.

“For a developing country, finding something new to export has major economic significance. It’s hard to go to Costa Rica or Columbia or Kenya and imagine what they would be like without coffee,” he says. The worldwide demand for coffee has shaped development in those countries, and biofuels could do the same.

“If the world finds a technology that will use a country’s sun, natural rainwater and willingness to work, and transform that into energy, this represents a significant economic opportunity,” he says. “When you find something that is a global product, it can be truly transforming for a country.”

Using satellite data, Hausmann and

others looked at Brazil, which already is busily growing sugarcane for biofuels. He crossed out the Amazon basin, and calculated the remaining land with good soil and adequate rainfall.

"Excluding the Amazon basin, Brazil has 150 to 200 million hectares [370 to 494 million acres] of arable land. Only 50 million of that is under production, of which 8 million is sugar cane," he says. "Brazil could triple its production without touching the Amazon forest."

He has found similar excess of land elsewhere in Latin America and Africa, he says. He and colleagues at the Harvard Kennedy School are looking at how biofuel production might work in four

developing countries: India, Brazil, the Dominican Republic, and Tanzania.

"The world has, in developing countries, ample high quality farming land that is not being used, or not being used productively. Biofuels could be an important industry for those countries to integrate into the global market."

Hausmann sees biofuels based on crops as a "stepping stone" to economic development. Sugarcane, for example, would be most efficiently processed near the growing fields, which means constructing a factory that brings jobs to a rural area. The product would then need to be transported, which requires new roads or rails. It might then need to be exported, which means building port infrastructure to handle shipping.

"It's a bit of a chicken and egg thing," he says. "You don't develop a capability to export unless it's needed for something useful." The global thirst for fuel, he says, would make biofuels very useful.

Hausmann's vision would likely make tropical countries that have underutilized land, labor, and rainfall the chief suppliers of biofuel to the world. More than just technology and infrastructure would be needed, however. Connecting a developing country to a global requirement is predicated on free trade, legal structures, and certification of the biofuel.

And, for the United States, it would require an end to protectionist barriers that have allowed American agriculture to reap a bonus from the biofuels zeal. It also runs afoul of "energy security" hopes that biofuels could make this country

self-sufficient for its transportation fuels. Currently, the United States keeps low-cost cane ethanol out of this country with a 54 cents-per-gallon tariff, even though the cane-derived ethanol is produced much more efficiently.

"If there was a global market for bio-ethanol, sugarcane would displace corn in no time," Hausmann says. He has little patience for the argument that the forestlands and

pastures of developing countries should not be cultivated to preserve their biodiversity and keep the stored carbon intact in the land.

"When the United States and Europe decided to deforest their woods for development, nobody said you can't do it. The notion that the world would be a cleaner place if we kept the world poorer, isn't persuasive to me." Besides, he argues, developments in agricultural technologies and such techniques as "no till" agriculture can minimize some of the erosion and environmental problems of growing crops. And just the potential of growing crops for biofuels would help the poor, he says.

In Venezuela, "you have millions of hectares of land now being used" for grazing cattle, sustaining less than one cow per three hectares. If we found something that would make that land more useful, that would represent an enormous increase in the value of the land."

"Technology is moving," he says. "We are at the Betamax phase of energy."

The search over how to realize the potential of biofuels is being done in the larger shadow of urgent need. Transportation accounts for two-thirds of the oil we use and one-third of our country's total carbon dioxide emissions. Even supporters of biofuels speak of success in terms of fractional

reductions of total demand. Higher fuel mileage standards, more conservation, and continued work toward electric or hydrogen cars to replace our existing fleet, they say, will still be needed.

"I think it would be ill-advised to ignore the potential of biofuels, and equally ill-advised to ignore the challenges," says Lee. "The key is that you don't put all your eggs in the same basket. You try to invest in a host of things. I don't think biofuels will in any way completely replace fossil fuels. But if I can make a dent at 20 percent of the fuel used for transportation...that's pretty good."

The competing approaches for making biofuels, and the obstacles confronting each, make the task of deciding which is best daunting. That is how it should be, says Church. Government should not repeat the mistake of corn ethanol, he argues. Instead, it should let competing technologies go forward to see which ones work.

"It should not be a policy issue," he contends. "If you just go from one initiative to another where you are providing funding, you can get into trouble. It's better if the government says, 'we aren't going to force specific biofuels, we will just buy it when it comes out.'"

Holbrook agrees. "What is scary about ethanol support was the government saying, here is the winner, rather than letting the facts on the ground—all of them—dictate," she says. "The worst case would be assuming that biofuels will solve all of our fuel demands so we don't have the will to do anything else."

Robert Lawrence, an economist at the Harvard Kennedy School, says we must decide just what we want out of biofuels. The rush to embrace corn ethanol came about through an odd marriage of environmentalists, security experts seeking reductions in oil imports, and the agriculture lobby, he says. Ultimately, all were disappointed: environmentally, corn ethanol is not helping stop climate change; with respect to energy security, it can replace only a small fraction of petroleum-based fuels; and the chief farm beneficiaries are big agri-businesses that make use of large economies of scale, while small farmers buying feed for livestock see their costs go up.

Lawrence believes the promise of biofuels will be realized only if policy makers can reach widespread consensus on a goal. And that clarity, he says, has to involve

"There's a real tension in the developing world between food and fuel. If you begin to shift farmland from food production to fuel production, that's a real problem."

the understanding that development of biofuels will not come cheap.

"How are you going to develop that new technology? Who is going to pay for it? The best way to do it is to make carbon expensive, to make the other alternatives more attractive. So let's not kid ourselves," he says. "We will have more expensive fuels, not cheaper ones," in the short run.

The roller-coaster ride of oil prices has steered policy, the public, and the pursuit of alternatives, Lawrence says. Each shock of high oil and gas prices—in 1973, in 1979, in the early 1990s and again in 2007-08—has led to an outcry

to end our dependence on oil. But each outcry diminished as soon as oil prices fell. Consumers went back to driving big cars, and fledgling plans for alternative fuels withered as they became unprofitable compared to cheaper oil.


Lawrence and Hausmann have proposed setting a floor price on oil—say \$55 a barrel, with a variable tax that would keep the price from falling below that. The floor would guarantee a steady target that would allow investors in new biofuel ideas to go ahead with their projects, confident that a plunge in oil prices will not undermine their plans.

"We've been shocked once, twice,

three times," he says. "How many shocks do we need?"

With demands for energy and transportation fuels still growing in this country, biofuels will almost certainly be needed even if they don't provide a complete answer.

"I just don't see how we are going to get there without some contribution from biofuels," says Schrag. And the tumultuous business of figuring out which ones are better is a necessary one.

"It's going to take hundreds and hundreds of interesting new ideas," Schrag says, "to create something that might work." 

Getting to Yes on Carbon

For policy makers, the problem of climate change has proven exceptionally vexing. Sharply reducing greenhouse gas (GHG) emissions will require nations to make large-scale changes to their energy, manufacturing, and transportation systems. And they will have to grapple with the knotty issue of equity—determining who should pay to reduce GHG emissions when wealthy countries are responsible for most historic warming, but developing countries are overtaking them as the world's largest emitters.

The international climate change treaty known as the Kyoto Protocol reflects some of these challenges: it requires only industrialized countries to make reductions (although these are relatively modest compared to the scale of the problem: 5.2 percent on average below 1990 emissions levels). Still, the Protocol has several notable features, including market-based provisions that allow nations to trade emissions allowances and to partially fulfill their reduction targets by funding GHG reduction projects in developing countries. The treaty's focus on emissions from wealthy countries reflects strong international consensus that industrialized nations have the means to act first.

But the Protocol also has some well-noted weaknesses. Not only

does it have a short time horizon (its provisions cover the period from 2008 to 2012), but many of the world's largest emitters, including the United States, China, and India, are not participating. It also offers only weak incentives to developing countries to participate (they can host clean development projects that reduce GHG emissions and generate marketable emissions reduction credits). Moreover, critics say that some of its trading provisions do little to reduce GHG emissions. Looking beyond 2012, many climate experts have called for a different approach that will spur more nations to participate and that will move all nations onto lower-carbon growth paths.

The Harvard Project on International Climate Agreements is one institution mining the possibilities. Directed by professor Robert N. Stavins (formerly co-director with Joseph E. Aldy, now

serving in the White House as Special Assistant to the President for Energy and Environment), the Project is an interdisciplinary initiative drawing on leading thinkers from academia, government, industry, and non-governmental organizations to identify key design elements of an effective post-Kyoto framework. This broad-based approach is critical because "climate change is an incredibly difficult problem, and no school or discipline or sector has cornered the market on wisdom," says Stavins, an environmental economist.

Already, the project has produced a book, *Architectures for Agreement* (Cambridge University Press, 2007), and a series of discussion papers by authors from around the world on issues facing climate negotiators. As these studies make clear, experts from different disciplines use independent criteria for assessing international agreements. Political scientists may focus on the number of participating countries, while economists measure compliance costs and lawyers

weigh how to justly distribute benefits and burdens among nations.

Seeking to reconcile varying approaches, the

ROSE LINCOLN PHOTO/HARVARD NEWS OFFICE



Robert N. Stavins, director of the Harvard Project on International Climate Agreements. Stavins is also director of the Harvard Environmental Economics Program, and Albert Pratt professor of business and government at Harvard Kennedy School.

project has identified four promising structures for a post-Kyoto agreement, though the recommendations are far from complete. The first would develop targets and timetables for emissions reductions through 2100 by creating a global system under which signatory nations would cap GHG emissions and trade allowances. To achieve an equitable distribution of costs, the plan would include provisions such as requiring larger reductions from industrialized countries in the early years and limiting national targets to fixed percentages of each nation's GDP. A second approach focuses on domestic policy, seeking to harmonize efforts at controlling emissions from individual market sectors through a series of linked agreements among participating nations. It would also include agreements to work together on new low-carbon technologies and to help developing countries adapt to climate change impacts. A third tactic invokes one of the simplest proven means of reducing fossil fuel consumption, and hence GHG emissions: through a tax. By establishing a system of national carbon taxes, this approach would give sources a direct incentive to reduce emissions. A final strategy would seek to coordinate national policies by linking existing carbon permit trading systems. World carbon emissions trading generated some \$60 billion in annual revenues in 2007. While 70 percent of it came from the European Union's Emissions Trading Scheme, other nations are creating domestic trading systems, as are several regional groups of U.S. states and Canadian provinces. Linking these markets would lower costs and make allowance prices more stable.

Whatever shape a post-Kyoto global strategy takes, there is broad consensus that it can only work if more nations take part. As Stavins and Aldy observe in *Architectures for Agreement*, "No policy architecture can be successful without the United States, Russia, China, and India taking meaningful actions to slow their greenhouse gas emission growth and eventually reduce their emissions." But different economic and political realities among nations imply that having a range of options available at the negotiating table—and perhaps even considering a mix of approaches—will be an important basis for broad participation. 

FACULTY PROFILE

Christoph Reinhart

Christoph Reinhart has been at Harvard's Graduate School of Design as an associate professor of architectural technology for less than a year, but his will soon become a familiar face. Under the auspices of the Office for Sustainability, Reinhart will tour campus structures this summer, on a quest to better understand a day in the life of Harvard's buildings.

Sensors, monitors, and human observation will tell Reinhart when the lights go on, how much sunlight comes in, the temperature on the thermostat—the kind of data necessary to help the school achieve its self-mandated 30 percent reduction in greenhouse gas emissions by 2016.

Reinhart's early academic work was in physics—particularly focused on the study of solar energy cells—but a chance revelation turned his attention to structural design. "I remember reading that color played a more important role than efficiency in the architect's choice of solar cell," says Reinhart with a laugh. "It was sobering to hear when you are spending all of your time making the [solar] cells better." After earning his Ph.D. in architecture, he joined the National Research Council of Canada and began his study of the life of dwellings and the behavior of people who use them.


His work is, in part, a return to his roots in physics—now applied to structures rather than solar cells—working to figure out how energy flows within buildings, with due consideration for the human element. "We want to find out how things like lighting levels affect people, and how people interact with the building," says Reinhart. Much like this summer's planned observations, these field studies begin with a look at the occupant's general attitude towards

their surroundings, followed by a study of their energy use.

Informed by his years of conducting such studies and a few thousand modeling exercises, Reinhart recently completed a set of structural baselines for architects looking to include elements like natural light into their structures. To determine how deeply daylight will reach into a room, for



example, architects need to use specific calculations based on the window's height—an objective guideline to replace varying rules of thumb.

Reinhart hopes to inspire in his graduate students the same kind of desire to question the established wisdom. "I really want them to be able to critically assess a building," says Reinhart. "To be able to say, 'Well, what they claim with this green building—does this really work?'" Part of the reason why the environmental movement and green buildings are at the forefront right now is a matter of energy efficiency, he says. "It's also the promise that these buildings can lead to healthy and more productive people." In other words, good green design isn't just for the health of the planet. 

—Dan Morrell

The Energy Edge

Three junior faculty members grapple with the world's energy problem

by Doug Struck

Conviction came to Alán Aspuru-Guzik at a campus lecture. "It was a tipping point," he recalls, when in 2005 he heard Sir David King, then science advisor to the British prime minister, talk on the need for action on global warming. "I thought, 'A scientist has to do something about this.'" At the time a post-doctoral researcher at the University of California at Berkeley, he went to dinner with friends, and told them, "Guys, what we are doing is a little bit too removed."

Now an assistant professor of chemistry and chemical biology at Harvard, Aspuru-Guzik, 32, is among a group of young Harvard faculty members who are

confronting the most challenging frontiers of science to help solve the world's energy dilemmas. These young researchers are likely to show up at the lab in sweatshirts and sneakers, write a blog at night, and have their own profiles on Facebook. But they are also tackling the twin threats of climate change and energy demand—inventing new materials, plumbing the very essence of old ones, and harnessing novel techniques in pursuit of a new era of energy. In doing so, they are leading a generational change, as successors to the scientists who earlier revolutionized society through transistors and microchips.

"Twenty years ago when I started

teaching here, nobody talked about energy," says Michael Aziz, 52, a professor of materials science. "It was the era of cheap oil, and energy was a non-issue." As our energy problems have emerged more clearly, that has changed, he says. "Now, many want to go into it."

Quantum Quest

Aspuru-Guzik saw potential in bringing the emerging field of quantum computers to bear on his energy research. Quantum computers, which have the ability to juggle alternative outcomes, are better than even the best binary computers at solving certain kinds of problems. They may prove effective at predicting the outcome of chemical reactions, a function that can quickly overwhelm traditional computers.

Scientists using chemical

reactions to explore new materials and find novel synthetic compounds now work largely by trial and error, or run computer simulations that take exponentially larger amounts of time as the complexity of the reaction increases. "We're hoping that quantum computation will bring new methods of simulating molecular systems," he says. Potentially, this basic research has broad applications, from drug discovery to the engineering of materials useful in energy research.

Aspuru-Guzik leads a team that is looking, among other things, at creating plastic solar cells. Plastics—made of organic materials in a thin, flexible film—can have photovoltaic properties. But they have much lower efficiency than traditional silicon-based photovoltaics, which convert 15 to 20 percent of the sun's energy. And organic plastics degrade in sunlight, giving them a short lifespan.

Aspuru-Guzik decided to try to create a material that is more efficient, cheaply made, and has greater durability than anything available today. In photosynthesis, he knew, plants are amazingly efficient at transferring molecules in the first, almost-instantaneous step in the process of converting sunlight to energy. He also knew that many plants have the ability to protect themselves from harsh sunlight.

That set him on a search for a synthetic material that could more closely mimic the abilities of plants. The right material, he theorizes, would have a greater efficiency in transporting charge and electronic excitations and be less susceptible to degradation. If materials with those advantages could be found, they might lead to a new breed of portable electric power sources that could be used anywhere. The compounds studied by Aspuru-Guzik have the potential for use in sensors, mobile communications technology, and "organic electronics" that could be easily deployed even in remote locations.

But to find that material through trial and error would be a quixotic search. Instead, Aspuru-Guzik and his team have seized on a creative research idea. They have partnered with IBM in a project called the World Community Grid to enlist thousands of idle personal computers. Anyone agreeing to help can download a screensaver at <http://cleanenergy.harvard.edu/go/> that will join their computer, when not in use, with



Alán Aspuru-Guzik, an assistant professor in the department of Chemistry and Chemical Biology, is looking for a cheaper and more efficient alternative material to produce solar cells.

an army of others working through the calculations of Aspuru-Guzik's search for improved molecules and polymers.

"In the first year, we expect to use 4,000 computer-years. That's equivalent to having a supercomputer dedicated to our lab," he says. "We will be able to examine the properties of 100,000 synthetic compounds a year.

"Right now, doing energy research is very aligned" with the world's greatest social, political, economic, and scientific problems. "We are all thinking about what to do with climate change and energy sources and energy independence," says Aspuru-Guzik. He and some of his fellow researchers at Harvard "are just a little bit ahead of the curve, but there will be a massive rush into these fields. I think there will be a generation of young scientists all over the world thinking about this."

Solar Savior

Ted Betley was thinking about the future as he toiled as a frustrated chemical engineer in several short-term stints with large companies. "I ended up being a glorified plumber," says Betley, 31, a Michigan native. "The work I was doing was 'what diameter of pipe would affect what product distribution.' I wasn't getting into the chemistry."

More to the point, he wasn't getting into the magic at the heart of many chemical systems that intrigued him the most: the catalyst. The catalyst is the spark of chemistry, the process that accelerates an otherwise routine reaction so that it happens quicker, better, easier, or cheaper.

"That's where the action is," Betley says. "I wanted to know what was happening in the catalyst. If you know how to manipulate atoms and molecules, you could be on the cutting edge."

He pursued that knowledge at the California Institute of Technology, at MIT, and then at Harvard where he set up a lab in 2007 as an assistant professor in chemistry and chemical biology. Working with a research group of seven students, Betley spends hours with his hands plunged through rubber gloves into an airless lab chamber, "shaking beakers," he says with a grin.

One of the puzzles they are trying to solve is how to devise metal catalysts that produce hydrogen efficiently enough that it could be used in fuel cells for cars and homes. Many see hydrogen as a

FACULTY PROFILE

Peter Bol

Peter Bol's interest in technology was borne of necessity. In the late 1970s, Bol was working on his doctoral dissertation at Princeton. Terrible with a typewriter, his only option was a "mainframe" computer—with a rudimentary word processor—which allowed Bol to correct his numerous errors. "I have been interested in [technology] since then, because it seemed that it allowed you to do things that were otherwise terribly time-consuming," says Bol.


Some thirty years later, Bol—now Carswell Professor of East Asian Languages and Civilizations—still recognizes the importance of technology, not just as a time-saver, but as a tool. As an expert in Chinese history, Bol became interested about a decade ago in what historians could learn by considering not just chronological data, but spatial information as well. "Historians look at change over time in a society and try to account for it," he says. "But human experience and life unfold through space as well." Using computerized Geographic Information Systems (GIS) applications, Bol found he was able to correlate layers of data and perform analysis otherwise impossible. "I pay attention now to things like spatial variation, and try to see how that relates to time," he says. "It's adding something new—a variable I wouldn't have otherwise considered."

Bol recently wrapped up a nine-year-long China Historical GIS project, a database that tracks Chinese history from 222 BC to 1911. He also serves as the director of Harvard's Center for Geographic Analysis, which operates as a support service for University faculty, allowing them to launch projects like an interactive map of Africa, which offers—among seemingly infinite options—the ability to chart the geographic origins of different works of art on the continent.

In addition to offering a broader understanding of history, Bol says GIS has become a powerful instructional instrument. He saw evidence of this during a recent speech in Florida, in which he presented an animated map showing the disappearance of the state's Gulf Coast as sea levels rose. A man in the audience was outraged, labeling Bol a partisan and the presentation "propaganda." "I think what got him particularly upset is that [the audience] could see this happening," he says. "And they could see that where they were at that moment was going to be gone."

It's the kind of environmental lesson that China—which recently overtook the U.S. as the world's leading carbon

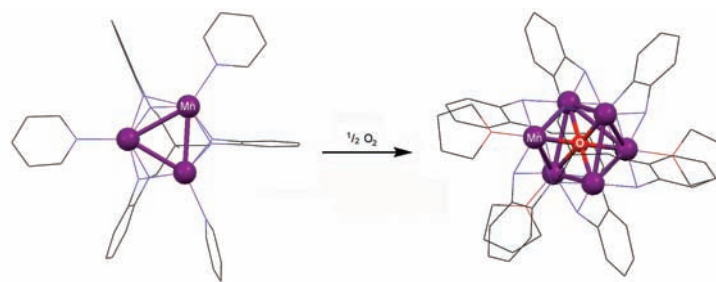


polluter—could use. Bol notes that the Chinese historically did not subscribe to the worldview that the earth was made to serve them, instead seeing themselves as connected with the environment. The acceptance of a Western notion of "conquering" nature in the name of progress changed this, says Bol. But the idea is now coming into question. "There are lots of people in China who are looking at this and saying 'this isn't sustainable—we can't go on like this,'" he says. "And when the Chinese come to America and they see the stars at night, they say, 'Wow—this is what it is supposed to be like.'" 

—Dan Morrell



Ted Betley, assistant professor in the department of Chemistry and Chemical Biology. Betley is attempting to recreate the process of photosynthesis to unlock the potential of hydrogen as a viable alternative energy source.



Tri-metallic complexes allow for cooperative reaction chemistry.

COURTESY OF TED BETLEY

that, in effect creating artificial photosynthesis. The industrial approach is crude and wasteful, he

emphasizes, a “sledgehammer” compared to the elegance of nature. “There’s a big disconnect between what nature can do at ambient conditions, and what we have to do to get the same result.”

Replicating photosynthesis is a grail long sought in inorganic chemistry. Many researchers have tried to find a single chemical reaction that does the job. But Betley is instead experimenting with a method that uses multiple metals to build molecular scaffolding. This approach lines up the atoms to order a series of small reactions

that imitate the step-by-step process used in the chloroplasts of photosynthesis. Using a cluster-like molecular structure as a stage, the ensuing chemical teamwork may use far less energy overall than a single agent. “The way to do it more efficiently,” he says, “is a cooperative effort that frees the atoms needed to break down water into hydrogen.” If this puzzle could be solved, Betley says the ultimate payoff might be “to stop importing oil.” He imagines households with solar cells that drive his chemical process to turn water into hydrogen, with the gas then stored in fuel cells.

The energy payoff would be enormous. “We are really, really encouraged that we are looking down the right road,” he says. “Potentially, it could take people off the grid. It’s not going to be a silver bullet, but it would be cracking into a vast energy source.”

A Thin-Film Future

At his Rowland Institute laboratory, three miles down the Charles River

breakthrough energy storage system for the future, but right now, industry uses natural gas and steam to produce hydrogen, in a process that is expensive and energy intensive. Nature does it with sunlight and water. Betley wants to replicate

Fellows Announcement

For the past three years the Center has recruited some of the best of a new generation of environmental scholars to work with Harvard faculty mentors on the most important environmental challenges of our time. Together, the Environmental Fellows at Harvard form a community of researchers with diverse backgrounds united by intellectual curiosity and top-quality scholarship. In addition to working closely with their faculty hosts during their two-year appointments, Environmental Fellows broaden their perspectives through frequent group meetings and the Center’s Environmental Fellows dinner series, which features faculty-led discussions on a wide variety of environmental topics. Past Environmental Fellows have gone on

to teach at Harvard, Ohio State, UC-Santa Barbara, and the University of Michigan.

Returning are second-year Fellows Etienne Benson, William Boos, Susan Cameron, Mauricio Santillana, Alex Wissner-Gross, and Shengwei Zhu. For more information about the Fellows program, visit the Center’s website: www.environment.harvard.edu/program/index.htm. The incoming 2009 Environmental Fellows are:

Joseph Cullen

Joseph Cullen is an economist who studies the interaction between government regulation, business



decisions, and the environment. He will work with Ariel Pakes in the Department of Economics to study the relationship between firm behavior and environmental policy, specifically to understand the long-run implications of wind power in generating capital on electricity grids. He will also investigate the implications of pollution-permit banking provisions in environmental regulations on environmental outcomes in the electricity sector.

Rafael Jaramillo

Rafael Jaramillo is a solid state physicist pursuing the development of new sources of energy. He will work with Shriram Ramanathan (SEAS) to understand



“Before, energy research was not a high priority. But now, energy is on everybody’s mind. The environmental concern...will stand the test of time.”

from Harvard’s main campus, Shriram Ramanathan and his team of ten researchers work to understand the invisible and intricate details of the meeting of oxygen and other materials. With furnaces at high temperatures, with probes at low oxygen pressures, with electron microscopy and with an array of homemade instruments that crowd his lab, they study oxides—the combination of oxygen with metal. What happens at the surfaces of that union and within the resulting oxide determines much about the physical properties of such compounds. And those properties are of immense interest for future energy technologies.

Ramanathan is trying to understand how molecules of oxides are arranged, and how they change as a material is made thinner and thinner. He and his researchers use a “sputter gun” to knock particles onto a thin surface, creating a nano-thin film. They lithographically create patterns on the film, and then etch away the underlying support material to create windows giving access

to the delicate film. With probes and atmospheric chambers, they can then examine its characteristics.

The structure of the molecules, the spaces between them, and even the defects in the material determine how fast, or slow, electrons are transported, and how charged particles make their way through it.

“By varying the thickness of the film, you can change the profile of the elements, and change the local electrostatic properties,” he says. Apart from the science, there are challenges in manufacturing films so thin that they allow some gases to pass through, while others are blocked. “We are talking about atomically thin materials with perfect continuity and no defects,” he says.

Just as development of transistors and semiconductors unleashed a flood of electronic technologies, development of new oxide materials with exotic properties could have dramatic—and yet unforeseen—possibilities.

Ramanathan, 34, an assistant professor of materials science, came to Harvard

and control electron transport across thin oxide barriers, a problem with broad relevance to future generations of solar cell technologies.

Christopher Jones

Christopher Jones is an historian interested in the intersections between energy, technology, and the environment. He will work with Sheila Jasanoff in the Harvard Kennedy School to develop the policy implications of his prior research into the critical roles played by transportation infrastructure in creating new energy consumption patterns. He will also begin a comparative study of coal use in China, India, and the United States in the twentieth century.



Jacob Krich

Jacob Krich is a theoretical condensed matter physicist concerned with the applications of quantum mechanical properties of materials at the nanoscale to clean energy science. He will work with Alán Aspuru-Guzik of the Department of Chemistry and Chemical Biology to understand the role of quantum mechanics in organic photovoltaic materials at room temperature, which may have the effect of optimizing organic solar cell efficiency.



Ling Zhang

Ling Zhang is an historian studying the environmental and economic history of

What’s on our website

environment.harvard.edu



Visit www.environment.harvard.edu for up to date information on environmental events around campus, HUCE

faculty associates in the news, the Environmental Fellows program, funding opportunities, and more. To learn more about the programs reported on in this issue, also see:

Graduate Consortium on Energy and Environment

www.energy.harvard.edu/consortium

Harvard Institute for Global Health

www.globalhealth.harvard.edu

Harvard Project on International Climate Agreements

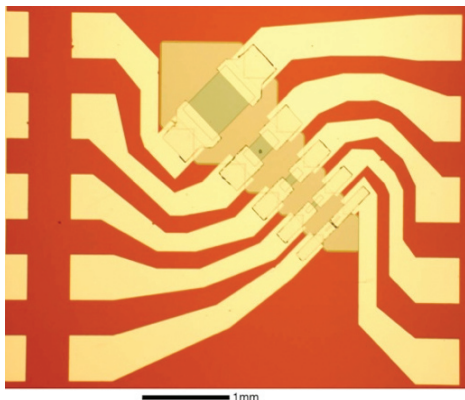
http://belfercenter.ksg.harvard.edu/project/56/harvard_project_on_international_climate_agreements.html

three years ago, on a path that began in Madras, India, where he studied metallurgical engineering, and that then led to Stanford, via the University of Houston. “He understands these materials more profoundly than perhaps anyone,” says Professor Aziz. At the moment, his team is building a hydrogen fuel cell—the

medieval northern China, with particular emphasis on the environmental problems associated with natural disasters and economic decline in traditional agricultural society. She will work with Peter K. Bol of the Department of East Asian Languages and Civilizations to deepen the understanding of the historical development of the environmental problems afflicting China in the present day.



The Center gratefully acknowledges the contributions of Robert Ziff '88; Lisa M. Henson '82; Joy Covey (JD '89, MBA '89); John French ('66) and Elaine Abbott French (EDM '73); and Gilbert Butler '59 to the Environmental Fellows Program.



technology some hope will revolutionize transportation—made of ultra-thin ceramics instead of precious metals, which would work at lower temperatures than current technology.

The solid oxide fuel cell could run on a variety of fuels, not just hydrogen, which requires energy to produce and must be stored under pressure. Ramanathan is making the fuel cells using electrolytes about 25 nanometers thick, about 4,000 times smaller than the width of a human hair. The thin structures would allow the fuel cells to run much cooler than similar cells with thicker electrolytes, and may make it possible to put them in cars

A test chip for variable temperature conductivity measurements on ultra-thin oxides.



and other vehicles. He has helped start a company, SiEnergy Systems, to bring the fuel cells to market.

But Ramanathan says that fuel cells are only one of the many applications of his research. His work could change electronics and solar cells, too.

“We could have new kinds of energy materials made out of thin films that could have completely different properties” than exist today, he says. “Very little is known about ultra thin membranes. Fuel cells are a natural

Shriram Ramanathan, assistant professor of materials science in the School of Engineering and Applied Sciences, believes thin film oxides are the key to the future of renewable energy sources.

application, but there are much broader implications.”

“Before, energy research was not a high priority. But now, energy is on everybody’s mind. The environmental concern,” he says, has raised it to a level of importance “that will stand the test of time.”

Environment @ Harvard

A sampling of the past year’s events.

Conferences and Workshops

F.O.R.E.S.T

March 5-6, 2009

Harvard University Center for the Environment

The F.O.R.E.S.T workshop was organized to discuss scientific and technological aspects of oxide materials for renewable energy. Lead organizer Shriram Ramanathan (SEAS) assembled a cadre of speakers to present on both the fundamental science concerning oxide surfaces and interfaces, and structure-property relations in energy conversion and storage.

Overcoming the Legal and Financial Obstacles to Deployment of Carbon Capture and Sequestration

March 30, 2009

Harvard Law School

Carbon capture and sequestration (CCS) has the potential to be an important tool for combating climate change, though at present there are significant legal and financial obstacles blocking its deployment. Wendy Jacobs, director of the Environmental Law Clinic, convened a select group of federal and state regulators, legislative staff, academics, finance experts, and industry representatives to develop solutions to these obstacles, and to explore the extent to which federal agencies should be responsible for the oversight or regulation of CCS.

Rapid Ice Sheet Destabilization: Past, Present, and Future

April 3-4, 2009

Harvard University Center for the Environment

The fate of the cryosphere and its implications for sea level and climate is currently one of the most challenging issues facing scientists as they attempt to predict future climate changes. In light of these challenges, Dan Schrag and Eli Tziperman (EPS) brought together leading climate scientists to discuss specific hypotheses of how ice sheets may have rapidly collapsed in the past, and the abilities and limitations of current models to predict such changes.

Ecological Urbanism: Alternative and Sustainable Cities of the Future

April 3-5, 2009

Graduate School of Design

The Ecological Urbanism symposium, hosted by the Graduate School of Design, assembled design practitioners and theorists, economists, engineers, environmental scientists, politicians, and

public health specialists, with the goal of reaching a more robust understanding of sustainable cities and what they might look like in the future.

American Environmental History: The State of the Field at Sea and on Land

October 17, 2008 and April 17, 2009

Charles Warren
Center for
Studies in
American
History
The Land and Sea



Joyce Chaplin,
director, Charles
Warren Center

Conference was a two-part panel discussion bringing together prominent scholars to consider current trends in environmental history.

Outdoor Air Pollution Expert Group Workshop

April 23-24, 2009

Organized by Professor Majid Ezzati (HSPH), this workshop examined the evidence for various concentration-response relationships for combustion-source air pollution.

Ongoing Series

The Future of Energy

Fall and Spring 2008-09

Students at the Center

Undergraduates form a vital part of the environmental community at Harvard, whether by being involved with student groups like the Environmental Action Committee, attending the Center's many seminar and lecture series, or participating in Center-sponsored environmental courses. For the past seven years, the Center has also funded undergraduate research projects—student-conceived projects that often lead to senior theses. In summer 2008, the Center

The Center gratefully acknowledges the contributions of Bertram Cohn '47, Barbara "B." Wu (Ph.D. '81) and Eric Larson '77, and William Haney III '84, to the Undergraduate Summer Research Fund.

began funding students' direct participation in research with HUCE faculty associates. This year the Center made awards to 19 students, encouraging their research related to environment. The students will pursue a wide array of innovative projects, such as the examination of drought policy in Hawaii, statistical analysis of North America's non-CO2 greenhouse gas emissions, investigation of invasive species in South Florida, and a photographic exploration of the influence of glacial history on the development of Boston. Further information about the program and past student projects is available on the Center's website: <http://www.environment.harvard.edu/resources/srf.htm>.

Since its inception in 2006, the Center's flagship lecture series, The Future of Energy, has offered high-level discussion and a broad spectrum of perspectives on the topic of existing and emerging energy policies and technologies. The speakers in the 2008-09 series maintained this tradition of excellence, representing such industries as nuclear, coal, and wind. The 2008-09 lineup of speakers featured: **John Rowe**, Chairman and CEO of Exelon Energy Corporation; **James Woolsey**, venture

capitalist with Vantagepoint Venture Partners; **Amory Lovins**, founder and director of the Rocky Mountain Institute; **Steven Leer**, CEO of Arch Coal, Inc.; **Saul Griffith**, President and Chief Scientist of Makani Power; and **Richard Garwin**, IBM Fellow Emeritus. The series is made possible with generous support from Bank of America, and all Future of Energy lectures are available for viewing online at www.environment.harvard.edu/events/futureenergy.htm.

Paul Zofnass establishes GSD sustainability initiative

Paul Zofnass '69, M.B.A. '73 has established a sustainability initiative at the Harvard University Graduate School of Design (GSD) with a \$500,000 gift. The initiative, The Zofnass Program for Infrastructure Sustainability, will support research and education to develop and distribute sustainability standards for large-scale development and infrastructure, similar to the U.S. Green Building Council's LEED standards for individual buildings.

"We are grateful for this generous gift and the exciting research it will

make possible at the GSD to further our commitment to sustainable design," said Dean Mohsen Mostafavi.

The gift recognizes Paul Zofnass' vision to better enable the design industry to promote and exercise sustainable design options and to enhance GSD graduates' preparedness to assume leadership roles in design practice throughout the world.

"I believe that a sustainable approach is critical to the design industry's ability to provide leadership in meeting the combined challenges of urban

development and environmental stewardship, and I would like to see Harvard be at the forefront of and the acknowledged leader of this effort," said Zofnass.

Zofnass is president of The Environmental Financial Consulting Group Inc., a New York City-based financial consulting firm that provides financial advisory and investment banking services to architecture and engineering companies serving the environmental infrastructure industry. He is a magna cum laude graduate of Harvard College and an alumnus of the Harvard Law School and Harvard Business School. Zofnass' wife, Renee Ring, is a securities attorney in New York City.

—Article courtesy of Harvard News Office

Biodiversity, Ecology, and Global Change

Fall and Spring 2008-09

The Center's second-longest running lecture series, Biodiversity, Ecology, and Global Change, brought some of the most prominent ecologists in the field to Harvard to discuss issues spanning the globe—from the effects of agricultural land use in Africa to climate change in Alaska, to the threat of invasive species everywhere in between. The 2008-09 speakers were: **David S. Wilcove**, Princeton University; **Terry Chapin**, University of Alaska-Fairbanks; **Daniel Simberloff**, University of Tennessee-Knoxville; and **Aaron Ellison**, Harvard Forest. This series is also supported by Bank of America, with lectures available for viewing online at www.environment.harvard.edu/events/.

Green Conversations

Fall and Spring 2008-09

Green Conversations is a uniquely formatted series of discussions with environment and energy experts. Rather than deliver a traditional lecture, the invited speakers make presentations

Comments

Do you have a comment you'd like to share? Send your thoughts to the Center for the Environment at huce@environment.harvard.edu, and let us know if you'd like to continue receiving this newsletter.

to the audience, and then engage in a discussion with selected faculty members who have expertise on the given topic. The 2008-09 series opened with the most distinguished guest of the series to date, His Excellency **Anoto Tong**, President of Kiribati. Tong discussed his unprecedented and ambitious plan to relocate Kiribati's 100,000-plus citizens, as the atoll nation prepares to become the first major victim of climate change-induced sea level rise. Also participating in the series were: **Max Page**, University of Massachusetts-Amherst; **Carol Dumaine**, U.S. Department of Energy; **Paul Ehrlich**, Stanford University; **Tom Baron**, formerly of the Massachusetts Water Resources Authority; **Richard Larrick**, Duke University; and **Anthony Barnosky**, University of California-Berkeley.

Special Event

Harvard University Celebration on Sustainability

October 20-24, 2008

Former Vice-President Al Gore gave the capstone speech at Harvard's weeklong sustainability celebration in October. The Harvard alumnus ('69), who in recent years has become a leading expert and advocate on environmental policy, delivered the annual Robert Coles Call of Service Lecture on October 22. Two days prior, the Center hosted a panel discussion moderated by HUCE Director Dan Schrag on "Reducing Carbon, Promoting Sustainability: the Role of Individuals and Institutions." Schrag engaged Kennedy School faculty William Clark, Kelly Simms Gallagher, Robert

Publication Note

SPRING / SPRING 2009

The Harvard University Center for the Environment (HUCE) encourages research and education about the environment and its many interactions with human society. By connecting scholars and practitioners from different disciplines, the Center for the Environment seeks to raise the quality of environmental research at Harvard and beyond.

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Photographer

Stavins, and Richard Zeckhauser in a lively debate over whether Harvard's institutional commitment to sustainability will have real impact on the attempt to mitigate the effects of climate change.