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The Path from Paris

What lies ahead for the global climate agreement

By Jonathan Mingle

In December 2015, more than 150 heads of state descended on Paris to attend the opening day of the 21st Conference of Parties under the United Nations Framework Convention on Climate Change (UNFCCC). When they departed, after many hope-filled speeches and handshakes, their negotiators were left to pursue an elusive goal: hash out a global agreement to put the world on a path to avoid catastrophic climate change.

After two weeks of exhausting negotiations—building on two decades of contentious talks going back to the first COP in Berlin in 1995—delegates from 195 nations emerged with a long-awaited deal. In the 12-page Paris Agreement (plus 19-page Decision), they embraced the aspirational goal of holding the global temperature rise to “well below 2 degrees C above

pre-industrial levels” and to pursue efforts to limit the increase to 1.5 degrees. And for the first time ever, every participating nation committed to slowing or reducing its emissions of climate-warming pollution.

“The Paris climate talks themselves were very successful,” says Robert Stavins, the Pratt Professor of Business and Government at the Harvard Kennedy School (HKS) and Director of the Harvard Project on Climate Agreements. “They provided the foundation for a new path forward. But whether ultimately the Paris



More than 150 heads of state gathered in Paris to attend the 21st Conference of Parties under the United Nations Framework Convention on Climate Change (UNFCCC).

Agreement itself proves to be a success—in terms of reducing emissions at what many people consider to be a desirable rate and at reasonable cost—no one knows the answer to that...because it depends upon how the Agreement is going to be implemented in 195 countries.”

The verdicts from experts across Harvard’s various schools and disciplines struck a similar note of cautious optimism, especially in light of the significant political constraints at work in countries around the world.

“Many people who are realists—both in terms of what the science has to tell us and what the experience and theory of international agreements have to tell us—say that Paris hit a somewhat sweeter spot than we would have reasonably expected,” says

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Letters from the Directors

Dear Friends:

I want to share the exciting news with you that Peter Huybers has agreed to join me in leading HUCE, becoming Co-Director for the duration of my term—which ends in 2018. Peter is a superb climate scientist with broad academic interests, who has been a part of the HUCE community since he first came to Harvard as a member of our first class of Environmental Fellows. After just a few months, he joined the faculty in Earth and Planetary Sciences, and now, ten years later, he is also appointed in the Paulson School of Engineering



and Applied Sciences. Peter has played a central role in many HUCE activities in recent years, participating in the selection committee for the Environmental Fellows, and

also serving as an informal advisor to me on all sorts of issues. I am very excited to be working with him in a more formal capacity, and I believe he will prove a wonderful source of new ideas and new inspiration in the years ahead.

HUCE is at a very exciting crossroads. Towards the end of the summer, we will move from our current location on the 3rd floor of the Museum building up and over to the 4th floor, in newly renovated space that will be roughly three times larger than our current space—you can see the pictures of the renovation

in progress on page 13. In addition to more seminar rooms and gathering spaces, the major new addition will be new office space for program activities, which we will use to support key academic areas. We hope to have abundant space for short- and medium-term visitors, and also to accommodate a variety of research staff including graduate students and postdocs. It will make HUCE an even more vibrant place to spend time, but it will also require more effort to oversee and nurture the various projects and activities that will use the space. I am grateful that I will have Peter to share the responsibility for developing this space, helping to create the tone as HUCE expands.

After twelve years of serving as Director of HUCE, I feel it is important both for me and for HUCE to pass the torch to encourage new ideas and new approaches. Our mission has always been focused on building our community, and making Harvard a more exciting intellectual place for environmental scholarship of all kinds. As Director, I have tried to build the Center in a way that does not depend on a single individual, and so a transition in leadership is an important step towards that goal.

To be clear, I am neither leaving HUCE nor retreating into the shadows. Over the next two and a half years, I will be working with Peter, side by side, to maintain and build our program as it expands into the new space. I have also taken on a new role as Director of the Program in Science, Technology and Public Policy in the Belfer Center at the Harvard Kennedy School, and I will be working in that capacity to develop a joint project with HUCE focused on climate and energy policy. And even after this last term as Director has ended, I will still be very much a part of HUCE, as I expect this new energy policy effort to continue. I have always envisioned HUCE as a vessel that supports many different activities within our community that are each championed by different people. I look

William Clark, the Harvey Brooks Professor of International Science, Public Policy, and Human Development at HKS. “It is a serious step in the right direction. But, like any international environmental agreement ever, it is but one step on a pathway. We’re not there yet. Our next step could easily go backwards. Aggressive efforts to stay on track are essential.”

Critics of the deal were quick to point out the troubling gap between the ambitious rhetoric and the con-

crete actions on the table: adding up all of the individual pledges at Paris still puts the world on a path toward a minimum 2.7 degrees C of warming. What’s more, those pledges aren’t legally binding. Countries will face no penalties for not following through on their “intentionally nationally determined contributions” (INDCs).

From this perspective, Paris looks like a collection of voluntary pledges that still fall far short of meeting the stated target. (Even 2 degrees C, some

scientists say, is too risky a threshold to cross.) And many of the key details—how countries will report on their progress and share information in a transparent way; how finance to assist with adaptation and mitigation will flow from developed to developing countries—remain to be worked out at future negotiations.

So why all the celebration and renewed optimism among longtime observers and participants coming out of COP21?

forward to throwing my efforts into one of these activities, and passing the larger responsibility for steering the ship to a new leader.

So please join me in welcoming Peter as our new Co-Director of HUCE. If you do not yet know him, I hope you have a chance to meet him soon. Most of all, I hope you will join Peter and me in working together to continue to build and strengthen the environmental community at Harvard. I am looking forward to the road ahead. 🌍

Sincerely,



Dan Schrag
Director, Harvard University Center for the Environment

Dear Friends:

I am honored to take on this new role as HUCE Co-Director.

In reading through the featured articles in this newsletter, I am reminded once again of the extraordinary environmental expertise of the HUCE community. In the cover story, you will hear about the prospects and implications of the historic Paris climate agreement from leading experts at the Kennedy School, the Law School, and the Paulson School of Engineering and Applied Sciences. The second feature on the future of solar power generation offers a variety of perspectives—some optimistic, others less so—with a focus on subsidies, scalability, and technology. The newsletter also highlights new initiatives like the Planetary Health Alliance, ongoing programs like the Environmental Fellows Program, and the lectures, seminars, and special events that bring together faculty, students, and the broader Cambridge community. These pieces illustrate why it is such an exciting point in time to join in leading HUCE.

On a more personal note, I have benefited greatly from the activities sponsored by HUCE over the last ten years. For example, when I arrived at Harvard ten years



ago, my research focused exclusively on past climates, but has broadened to include topics such as extreme weather and crop production as a result of the conversations and collaborations facilitated by HUCE. More generally, where my awareness of the scope of environmental issues has grown, it has been matched by a better appreciation of the contributions made by individuals across our community. The dedication and inspiration routinely on display at Harvard is a chief source of optimism in considering how we will address environmental concerns.

I look forward to working with Dan and the HUCE staff in continuing to support the vibrant environmental community at Harvard. 🌍

Sincerely,



Peter Huybers
Co-Director, Harvard University Center for the Environment

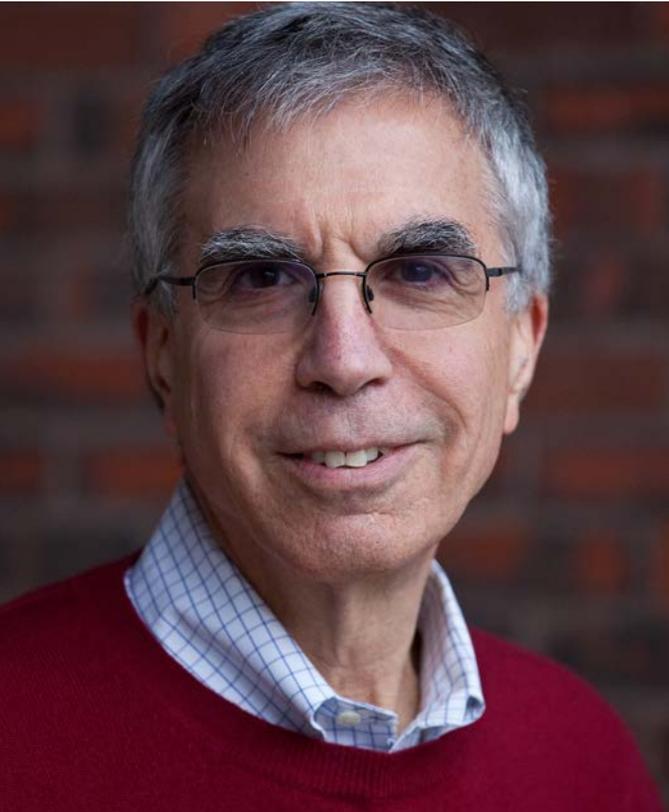
Stavins and others who view the Paris outcome as a success point to the structure the Agreement puts in place for potentially creating a virtuous cycle of increasing ambition among the participating parties.

In November, Stavins wrote a post on his blog outlining a “scorecard” for the upcoming talks. His checklist included five key elements: credible reporting and transparency requirements; coverage of 90 percent of global emissions; a system to finance

climate adaptation and mitigation; five-year periods to return to negotiations; and putting aside unproductive disagreements regarding provisions for “loss and damage” (the politically fraught proposal to compensate poorer nations for climate impacts such as floods, droughts, and other events).

All were achieved in Paris. These provisions, Stavins and other experts say, are far more important than the aspirational global temperature targets.

“The structure of the Agreement itself provides the possibilities,” Stavins says. That structure includes a few key components designed to encourage countries to increase the ambition of their voluntary commitments over time, from a “ratcheting” mechanism to “stock-taking” periods to a “floor” for yearly finance flows. They are also designed to pressure nations into translating those commitments into meaningful actions, through a so-called “naming and shaming” process



Left: Robert Stavins, Pratt Professor of Business and Government at HKS and Director of the Harvard Project on Climate Agreements; Below: Jody Freeman, Cox Professor of Law and Director of Harvard Law School's Environmental Law Program.

Breaking barriers

Whether it represents the culminating step of a 21-year process, or the first step on a new path—or merely another step on humanity's long journey—the Paris Agreement is a leap forward for a simple reason: each nation acknowledged its responsibility to reduce its share of the pollution driving climate change, and each pledged to act accordingly.

“That’s the breakthrough,” Stavins says. For

the first time, every country is pushing in the same direction. “Most importantly, the INDCs submitted under the Paris Agreement account for more than 95% of global emissions, compared with the 14% coverage of the Kyoto Protocol in its current commitment period.”

“That’s the fantastic part of Paris,” agrees Aldy. “It’s the first time we have a universal effort to mitigate

emissions, and universal agreement on participating and on transparency.”

This universal participation was made possible by a turn away from the approach enshrined in the Kyoto Protocol, produced at COP3 in 1997. Under Kyoto’s framework, only Annex I countries (developed countries such as the United States, Canada, Australia, and most European nations) were required to reduce their carbon output, while Non-Annex I countries (most developing nations, including fast-growing economies such as China, India, and Brazil) had no obligations.

This bifurcation was founded on the principle of “common but differentiated responsibilities and respective capabilities,” recognizing the fact that the United States and other countries that industrialized early were responsible for the bulk of historical emissions. Today, China is the largest emitter of greenhouse gases, and India is the third-largest polluter. Whether it’s fair or not (a question that proved to be a sticking point at COP21, as at every past COP), for any international effort to tackle climate change to be effective, these nations must play a central role.

“The world is fundamentally different today than in 1992,” notes Aldy. “Some countries that were developing back then now have higher per capita incomes, and higher measures on the Human Development Index, than

of reporting and review of emissions reductions. “If there’s adequate transparency of what emissions reductions are actually being achieved, that could provide the incentives to ratchet up commitments and actions over time.”

“There’s so much left unfinished after Paris, that’s true, but how optimistic you are is somewhat dependent on the baseline you start with,” says Jody Freeman, Cox Professor of Law and Director of Harvard Law School’s Environmental Law Program. “If your baseline is just starting with Paris, you’d say, ‘Look at all that’s left unfinished.’ If you start with the Kyoto Protocol, you’d say, ‘We’ve made tremendous progress,’ because you have the game-changer of China and India being in the process, being committed to emissions reductions.”

“For those who say this isn’t enough to get us to 2 degrees C, that’s been true of the previous 20 COPs as well,” notes Joseph Aldy, Associate Professor of Public Policy at HKS. “Everyone knows we’re taking a long path to get to whatever our climate stabilization goals will be. Let’s worry about taking the first step.”



some on the bottom of Annex 1. So why can't we expect these countries to do more? As much as we debate who is responsible, if developed country emissions go to zero tomorrow, and developing countries do nothing to change their trajectory, we'll go way past 2 degrees C warming." The Paris Agreement still acknowledges those "differentiated responsibilities," but largely leaves them behind in the nuts and bolts: in the most critical components such as transparency and reporting, every country has the same obligations.

The Paris deal marks a turning point in the UNFCCC process for another reason: unlike the Kyoto Protocol, the Paris Agreement is not a legally binding treaty. Some analysts worry that Paris' reliance on merely voluntary actions won't be enough to generate emissions cuts that are deep and fast enough to stay under the 2-degree C threshold.

"Whether the mechanisms that were agreed upon are actually going to produce the emissions reductions that we need is a little up in the air, because there is no clear enforcement mechanism," says James Stock, the Hinchings Burbank Professor of Political Economy. "On the other hand, having strong enforcement mechanisms is what prevented previous attempts from working. It's the best progress that we seem to be able to make at the moment."

But this distinction matters less than it might seem. Aldy points out that "calling commitments legally binding, and designing a penalty for noncompliance, is no more stringent or meaningful in terms of impact for promoting compliance. We can call them 'legally binding,' but still have countries like the United States that never ratify it, and still have countries like Canada pull out of Kyoto so it would not be found as not in compliance. At the end of the day"—even with a legally binding treaty—"it's only peer pressure that works."

How will we know that all of this is actually working? "The real test, over a five-year horizon, is do you start to see emissions go down?" says Stock. "This has to ramp up in a big way. (Staying under) two degrees is incred-

Joseph Aldy, Associate Professor of Public Policy at the Harvard Kennedy School.

ibly ambitious. Staying under 1.5 degrees would require an entirely different level of ambition, and eventually require carbon removal technologies."

The road to Paris

The path to Paris involved a few key turning points. One was the failure of the 2009 climate talks in Copenhagen, which were widely expected to produce a binding international treaty to take force when the Kyoto Protocol expired. Instead they ended in re-creation and a watered-down place-holder political accord brokered at the last minute by the U.S., China, and a group of other major economies.

In the wake of that disappointment, the new framework emerged, leaving behind the division between developed and developing countries and emphasizing a bottom-up approach, in which countries would put forward climate plans reflecting their domestic political realities and capacity to deliver.

"We saw the wall between Annex 1 and Non-Annex 1 countries start

"For those who say this isn't enough to get us to 2 degrees C, that's been true of the previous 20 COPs as well. Everyone knows we're taking a long path to get to whatever our climate stabilization goals will be. Let's worry about taking the first step."

to come down in Copenhagen," says Aldy. "You had some 40 developing countries submit goals and plans. That was never done before. We continued to see that in Durban (COP 17), where the mandate was negotiated that led to Paris, that tried to avoid this kind of split" between developed and developing countries.

"The official pivot point was the Durban Platform for Enhanced Ac-



BROOKS CANADY

tion, which said that all countries, all parties would be under a common legal framework," says Stavins. But he points to another event as the "real pivot point."

"I was in Lima for the negotiations the year before Paris, and countless times I was talking with different negotiating teams, and there were difficulties in negotiations over this issue or that, but you would sense that there was a wind pushing at their

backs, that kept them going—and that was the knowledge of the joint China-U.S. announcement."

Given that the United States and China together account for almost 40 percent of global emissions, any global effort was bound to fail without their leadership. In November 2014, President Barack Obama and President Xi Jinping met in Beijing and announced a bilateral climate agreement. The



James Stock, Burbank Professor of Political Economy.

United States pledged to reduce emissions by 26 percent below 2005 levels by 2025, while China promised its greenhouse gas emissions would peak by 2030, and that non-fossil sources like solar and wind would constitute 20 percent of its total energy production by 2030. These pledges would go on to form the basis of their respective INDCs at Paris.

The two leaders met again in Washington, in September 2015, to lay out the details of how they would achieve their goals. China surprised many observers by announcing the launch in 2017 of a national carbon emissions trading system covering key industrial sectors. The United States announced plans for more stringent efficiency

standards for appliances and vehicles, and plans for reducing methane emissions from landfills and natural gas infrastructure.

But the most significant component of the U.S. action plan was the Clean Power Plan (CPP).

The Clean Power Plan—high stakes decisions ahead

The path ahead for the U.S. to fulfill the promises it made at Paris ran into a sudden stumbling block on February 9 of this year.

On that day, the Supreme Court issued a stay of the Clean Power Plan (CPP), a rule put forward by the Obama administration to reduce emissions from power plants, which account for 40 percent of U.S. emissions.

The CPP requires states to develop

FACULTY PROFILE

Frank Keutsch

As an atmospheric scientist, Frank Keutsch directs most of his attention upward, literally and figuratively. But he got his start in science by venturing downward: exploring the old mines deep beneath Germany's Black Forest region, where Keutsch was born and raised.

"As a child and teenager, I spent lots of time outdoors, poking around, collecting things—rocks, plants, old tools," he recalls. "I especially liked going into the old silver and cobalt mines and finding materials with bright colors that stood out from the browns and grays of the soil, tailings, and decaying wood. It made me wonder what caused that range of colors."

That curiosity led him to study chemistry at Germany's Technische Universität München, and then doctoral work in physical chemistry at University of California, Berkeley. In 2001, he completed his doctoral work on the physical properties of hydrogen bonds and the quantum mechanical effects of their "tunneling behavior." At that point, Keutsch recalls, "I wanted to apply my studies in a way that could have concrete impact. I concluded that my knowledge of physical chemistry could most fruitfully be applied to understanding the atmosphere." He has raised an analytic gaze to the skies ever since: initially at Harvard as a Lecturer and Research Associate; then, from 2005 through 2014, at the University of Wisconsin, Madison,

where he rose to become the Tullock Professor of Chemistry and a faculty associate at the Nelson Center for Sustainability and the Global Environment.

Last year, he moved to Cambridge, becoming the Stonington Professor of Engineering and Atmospheric Science in the Harvard John A. Paulson School of Engineering and Applied Sciences, and Professor of Chemistry and Chemical Biology in the Harvard Faculty of Arts and Sciences. "I am increasing the role that climate plays in my research, and Harvard is unique in the depth of interaction among researchers working at the intersections of climate, environment, and atmospheric sciences," Keutsch observes. "It offers the perfect atmosphere—forgive the pun—for students doing applied research because it helps them understand the full context for the questions they're addressing."

Keutsch's work focuses on determining the influence of human activity on the chemical reactions occurring in the atmosphere around us. He has pioneered lab synthesis of key reaction intermediates, hydroxy-hydroperoxides, and studies their interactions as an indicator of atmospheric change.

Previously, atmospheric chemistry was hampered by the lack of practical techniques for analyzing the lower atmosphere's composi-



ELIZA GRINNELL / SEAS COMMUNICATIONS

tion. But Keutsch's group is reinvigorating the field: developing new methods for applying existing technologies; and creating highly effective ways of calibrating the instruments now emerging. One of their most exciting developments uses a "fiber laser"—an easily transportable version of traditional, immobile laser measurement systems. "Increasingly, researchers are employing our technology because it's both portable and sturdy: it doesn't get misaligned or require optical calibrating," Keutsch says. "It's become key to NASA's airborne research campaigns."

Indeed, the approaches created by Keutsch's group are enabling scientists to conduct studies throughout the troposphere. "Our ultimate goal is to determine anthropogenic influence on tropospheric chemistry globally—from urban areas to tropical forests and oceans to polar regions." 🌍

—Merrill Meadow

plans to meet tailored targets based on their unique electricity generation profile, with the goal of reducing overall power sector emissions by 32 percent from 2005 levels by 2030. Slated to go into effect in 2022, it also puts in place incentives and regulations to get states to switch to lower-carbon electricity generation, such as wind, solar, nuclear, and natural gas.

The Court's stay was an unprecedented move, pausing the regulation before a lower court had even heard the legal challenge from two dozen states claiming the EPA exceeded its authority under the Clean Air Act, and until the Supreme Court eventually rules on it. Many experts read the stay as a signal that the Court was likely to strike down the rule.

Then, just four days after the stay was issued, Justice Antonin Scalia died of a heart attack. A likely opponent of the plan, his passing left the Supreme Court in a likely 4-4 deadlock when it ultimately hears the case (which is expected, after the case is heard by the U.S. Court of Appeals for the D.C. Circuit court on June 2, and its ruling is likely appealed).

"If there's a tie in the Supreme Court, the lower court ruling stands," Stavins explains. "But it's conceivable the Court will decide that this is a very important rule that should involve all nine justices, and therefore decide to delay a decision." The deciding vote could then be cast by whoever eventually fills Scalia's seat. Senate Republicans, meanwhile, are refusing to hold hearings on the nomination of Judge Merrick Garland. "So whether or not there is a CPP of the stringency envisioned in the final rule may well depend on one thing," says Stavins, "who the next president is, because that will determine the 5-4 vote."

In a commentary for *Foreign Affairs* (March 2016), Freeman noted that independent estimates suggest the CPP accounts for between 30 and 40 percent of the expected emissions reductions outlined in the U.S. INDC, making it by far the most important component of the U.S. climate plan. "In short, meeting the 2025 target is not impossible without the Clean Power Plan. But losing it would be, by any fair assessment, a blow."

In the wake of the stay, several states have put on hold their plans to comply with the CPP. U.S. states aren't alone in taking a "wait and see" approach to how the CPP fares in the courts—much of the world is watching what happens to U.S. climate policy, as well. The possible loss of the CPP could pose a serious credibility problem for the U.S.—one that could undermine the Paris deal.

"I received many questions about this in Paris," Stavins says, "whether the U.S. would be able to achieve its targets and what would happen if there's a new administration."

"There is no question that the President's announcement of the Clean Power Plan last October was critical to the success achieved a few weeks

"There is no question that the President's announcement of the Clean Power Plan last October was critical to the success achieved a few weeks later in Paris. I expect the Supreme Court's stay of the Plan, pending judicial review, has raised more than a few eyebrows in the capitals of other nations, and concern as well."

later in Paris," says Richard Lazarus, the Howard and Katherine Aibel Professor of Law, and an expert on environmental law. "The Paris Agreement would not have happened without it. I expect that the Supreme Court's stay of the Plan, pending judicial review, has raised more than a few eyebrows in the capitals of other nations, and concern as well."

Whether that apprehension will



Richard Lazarus, Aibel Professor of Law at Harvard Law School.

translate to reduced ambition in those other capitals is an open question. Lazarus has conducted oral arguments in 13 cases before the Supreme Court, and has closely analyzed the

Clean Power Plan. He has submitted a "friend-of-the-court" brief in the case, representing two past EPA Administrators who support the plan. "Our system of judicial review and such judicial intervention is likely so different from the way their own systems of government operate that it is hard for them to be sure of the significance (or not) of the Court's action," Lazarus says. "There is not yet any formal

indication that the Supreme Court's action here in the U.S. will hinder the positive momentum towards that historic result achieved in Paris. And certainly U.S. officials are working now to provide reassurance. Only time, however, will tell."

Domestic policies critical

Stock, who served as Member of President Obama's Council of Economic Advisors, sees the CPP as an

The outcome of the U.S. presidential and congressional elections this year are likely to have a broader impact on the prospects for implementing the Paris deal than the survival of the CPP alone. "If our next president is opposed to taking meaningful action on climate, that obviously has a big impact on the international negotiations."

important part of the U.S. pledge—and by extension, of the international momentum—but points to other independent economic factors that are bringing about emissions reductions domestically.

"There's a tailwind in the form of extremely low domestic natural gas prices," he says. "These low prices are resulting in an ever-increasing amount of substitution of natural gas for coal—that has nothing to do with the Clean Power Plan. So there's a significant reduction just from the economics."

He also cites other helpful tailwinds: the plunging cost of solar energy and the recent extension of the production tax credit for wind energy and the investment tax credit for solar, in the budget agreement passed in a rare moment of bipartisanship at the end of 2015. Together with the CPP, these tax credits are expected to significantly boost renewable power capacity in the coming years. "Those things together will make a great deal of difference between now and 2025."

But Freeman points out that the CPP isn't the only component of the U.S. climate plan plagued by uncertainty. "The pledge is based substantially on commitments that will fall to the next administration. Some policies haven't even been adopted by agencies yet, like regulating (methane) emissions from existing

oil and gas facilities. Some have been partly implemented but still could change, like the CAFE standards (for vehicle fuel economy), which are supposed to double by 2025. The EPA must conduct a mid-term evaluation of these standards by 2018 to decide whether they are still reasonable for cars planned for 2022-2025. So the question is, will they backslide or become more stringent? There is a lot of uncertainty about the policies that are

the basis for our current pledge. We have to keep the foot on the pedal of executive action."

Meanwhile, Donald Trump, the presumptive Republican nominee in the ongoing presidential primary, questions the settled science that humans are causing climate change. He has criticized U.S. participation in the Paris talks, and pledged to roll back much of President Obama's executive actions to reduce emissions. But Stavins thinks that could be more difficult than he suspects.

"The most important element of the Paris deal is the bilateral deal between China and the U.S. And China and the U.S. have relations ongoing on a lot of things other than climate: national security, trade, monetary policy, and many other issues." Would he really risk these other interests, he wonders, "for the sake of a symbolic statement on the Paris agreement? Not only would it be unwise, I just think (or at least hope) it's something he wouldn't do."

"Most people would say that China is probably going to outperform what its INDC proclaimed, the peaking by 2030 of CO₂ emissions," says Stavins. (Indeed, there is an emerging consensus among researchers that China will peak by 2025 at the latest.) "Most people would also say, if there's a change of political party in the White House, that would almost ensure that

the U.S. will not achieve its INDC. It probably won't anyways—it's going to be very difficult for the U.S. to achieve it."

Freeman sees the outcome of the U.S. presidential and congressional elections this year as likely to have a broader impact on the prospects for implementing the Paris deal than the survival of the CPP alone. There is little doubt that a Republican administration could, and likely would, put the brakes on U.S. climate action across the board, and thereby exert a major drag on the hoped-for "ratcheting" effect of Paris.

"China is highly motivated," she says. "Their population is choking on air pollution. And the conventional pollutants causing their health problems are co-emitted with carbon dioxide, so controlling them both goes hand in hand. China also faces considerable risks from climate change, and is under pressure from the international community to join the global effort, but quite apart from both of those concerns, domestic political considerations are driving them to act."

China has responded to U.S. policy steps with their own commitments, she says. For example, we adopted the CPP, and they announced an emissions trading program. "Can the next U.S. administration maintain that virtuous cycle?" Freeman asks. "Even if the Supreme Court upholds the CPP, if you have a president who wants to slow walk it or take it apart, that's a real problem."

Aldy, who, like Freeman, served as an energy and climate advisor in the Obama administration, agrees. "If our next president is opposed to taking meaningful action on climate, that obviously has a big impact on the international negotiations," he says. "What happens with the Clean Power Plan doesn't matter as much. President Trump is a different story."

Transparency and trust

If the path ahead from Paris winds this year through the U.S. Circuit Court of Appeals and voting booths on Tuesday, November 8, it also winds through conference rooms in Bonn and Marrakech.

Those are the sites of upcoming meetings where delegates will continue to put flesh on the skeleton of the Paris Agreement. “That’s going to be a great deal of work,” Stavins says. Stavins and his colleagues at the Harvard Project on Climate Agreements plan to continue working to help diplomats and governments figure out how to link carbon reduction efforts such as cap-and-trade programs and carbon taxes between countries (among many other outstanding questions).

Looking beyond 2016 reveals just how contingent success will be on the acts of both individuals and institutions, on how many pieces must come together for Paris’ “ambition-ratcheting” apparatus to function as intended. In this apparent vulnerability to unpredictable events—and to the fateful decisions of individuals

and institutions alike—lies both the hope and danger of the Paris deal. If conditions are right, ambition could rapidly multiply. Or it could dissipate just as quickly.

The gap between what’s required to meet the 2 degrees target and the emissions reductions in the existing pledges can only be closed by a gradual “ratcheting up” of ambition among all of the Parties. The hoped-for ratcheting of ambition depends, in turn, on the “naming and shaming” of those countries that aren’t living up to their commitments. But that peer pressure won’t materialize unless there’s a common, transparent framework for reporting and comparing countries’ actions.

In lieu of concrete mechanisms to enforce emissions reductions, the Paris accord has a process called “pledge and review.” Beginning in 2020,

and every five years after that, each country will update their INDC or submit a new plan. Then, starting in 2023 and every five years after that, a “global stocktake” will take place, to review progress toward implementing the pledges.

What that looks like in practice remains to be seen. The details of how the transparency framework will function still need to be worked out. In deference to concerns from China, India, and other countries about potentially overbearing inspection regimes, the text of the agreement states that “the transparency framework shall... be implemented in a facilitative, non-intrusive, non-punitive manner, respectful of national sovereignty, and avoid placing undue burden on Parties.”

“This is going to be quite challenging going forward,” says Aldy. “A lot

FACULTY PROFILE

Elsie Sunderland

When Elsie Sunderland was 17, her hometown on the southern shore of Nova Scotia sought to create jobs for local fishermen—impacted by the collapse of local fisheries—by building a toxic waste incinerator. To alert the community to the potential health impacts of the plan, Sunderland petitioned local politicians, wrote Op-Eds, and launched a citizen’s group. “And that was it,” she was hooked on the environment. “I knew that’s what I was going to do with my life.”

As an undergrad in McGill University’s environmental science program, her fieldwork in the salt marshes of the Bay of Fundy and in the estuaries of Prince Edward Island included collecting historical data on heavy metal deposition from the atmosphere. “The idea that you could see a nuclear weapons testing signal that could be used as a dating horizon everywhere—including remote salt marshes in Canada—I thought that was so cool,” says Sunderland.

During her doctoral studies in Vancouver, Sunderland, an avid runner with an interest in environmental policy, traveled to Washington, D.C. to run the Marine Corps Marathon. While there, she stopped by the Environmental Protection Agency (EPA) and left with a job. She worked on formulating federal policies at the

EPA, including the first-ever regulation on hazardous air pollutants from coal-fired utilities. In the process, she learned about the interplay of politics and science. “Often, the impact of a scientific discovery is determined by public engagement on the topic,” she says.

This experience reinforced the importance of articulating an environmental issue’s impact on human health. One of her ongoing projects at Harvard is studying a hydroelectric dam under development in northern Canada that will negatively impact the hunting and fishing territory of three indigenous Inuit communities. The study indicates that the flooding required for the facility will substantially increase the concentrations of methylmercury—a potent neurotoxin—in the fish and marine mammals consumed by the local populations. In the northernmost community, which relies most heavily on local food, the project could push 60% of the population above the regulatory threshold for methylmercury exposure.

Toxicant exposures defy geography, says Sunderland. She co-taught a graduate course in the fall with Sadasivan Shankar, a visiting lecturer in computational science and engineering, that looked at how new technology has brought humanity in contact with an ever-increasing number of new materials. “There



are 84,000 chemicals used in commerce, and we have regulations for less than 100 of them,” says Sunderland. One solution is to press for innovations from material scientists, whose focus should extend beyond merely ensuring that a material exhibits desired properties into an exciting new field of designing materials without negative human health and environmental impacts. “The idea is that when you are engineering a new material, you should also screen for toxicity,” she says. “The number of materials that we are releasing into the environment is exponentially increasing.” As she knows from experience, public engagement and scientific creativity will continue to shape our impact on the environment in which we live. 🇺🇸

— Dan Morrell

of work needs to be done on how to implement transparency. The hard part of ‘pledge and review’ is the review, not the pledging.”

But if the institutions can be put in place quickly and effectively, transparency can generate multiple benefits. “Transparency, shining a light on what they’re doing, and learning what works, is critical to creating confidence that countries are making good faith efforts,” says Aldy, who has closely studied best practices for transparency in other international agreements, and their relevance for monitoring climate action. “Transparency is a mechanism to raise costs both domestically and internationally for leaders who fail to deliver. Transparency can also lower the cost

“As a scientist, my job is to help make these measurements ... If each of the countries of the world thinks that the world can know what they’re actually doing, that has a salutary effect on their commitments.”



of agreement over time, by highlighting what is good policy practice, what works well for reducing emissions, and promoting thinking about ways to export those to other countries.”

Measuring and monitoring

Beyond the need for new institutions and protocols, the current standards for carbon emissions accounting will need to be dramatically improved—“naming and shaming” cannot work without accurate estimates of actual emissions reductions.

“If you start to think about implementing any kind of global effort to reduce carbon emissions,” says Steven Wofsy, the Rotch Professor of Atmospheric and Environmental Science, “you need to know what the carbon emissions are, and where they are taking place, and what the underlying processes are.”

Wofsy argues that better measurements are needed to support the post-Paris framework. He points out that current estimates of emissions mostly come from “bottom-up” national inventories. These are developed by taking data on energy production, industrial processes, land use change, and other activities, and multiplying them by emissions rates per unit of activity. They are plagued by uncertainty, making it difficult to verify just how much

pollution a given country is producing.

“They’re not very good, and not spatially disaggregated. So there’s no way to look and say, ‘Here’s where we should turn in the policy domain,’” he says. “If you think about how will we really do this, how will we develop knowledge of emissions in a way that is spatially and temporally disaggregated, it turns out that there isn’t a magic bullet. Some has to be done from space, some by making measurements in the atmosphere, some by looking much more critically at these inventories. As a scientist, my job is to help make these measurements, understand these emissions, and provide tools for people. If each of the countries of the world thinks that the world can know what they’re actually doing, that has a salutary effect on their commitments. I have observed this time and again: as soon as you begin to discuss that you have or will have the capability to measure what people are doing, that kind of clears their minds.”

Wofsy sees the role of scientists like himself as helping fuel ambition and effective action, in keeping with the collective spirit of Paris—not as helping to penalize certain players. “We’re not the carbon police. We’re the eyes and ears of the policy makers, helping them do things, not trying to put them in jail.”

Wofsy notes that some countries simply lack the technical capacity, finances, and tools to do the detailed reporting of their emissions that the Paris regime will require going forward. In others, accurately determining how much pollution they are emitting is challenging for other reasons. “For instance, China has a lot of technical capacity, but they don’t have the ability to know their emissions—that’s more of a governance issue. If we’re successful in developing methodologies that allow us to do this from space, we can circumvent these sorts of issues.”

But Wofsy is concerned that remote sensing programs to support the monitoring Paris requires aren’t ad-

Steven Wofsy, Rotch Professor of Atmospheric and Environmental Science.

“This is part of a long process of humanity trying to come to terms with the fact that it is radically restructuring the environment it lives in, and in turn being restructured by those changes.”

vancing fast enough. “It’s not too late, but it’s not really happening right now. I don’t see a big push to do a significant step forward in remote sensing of carbon dioxide. It’s really incremental.”

Both an urgent task and a “long game”

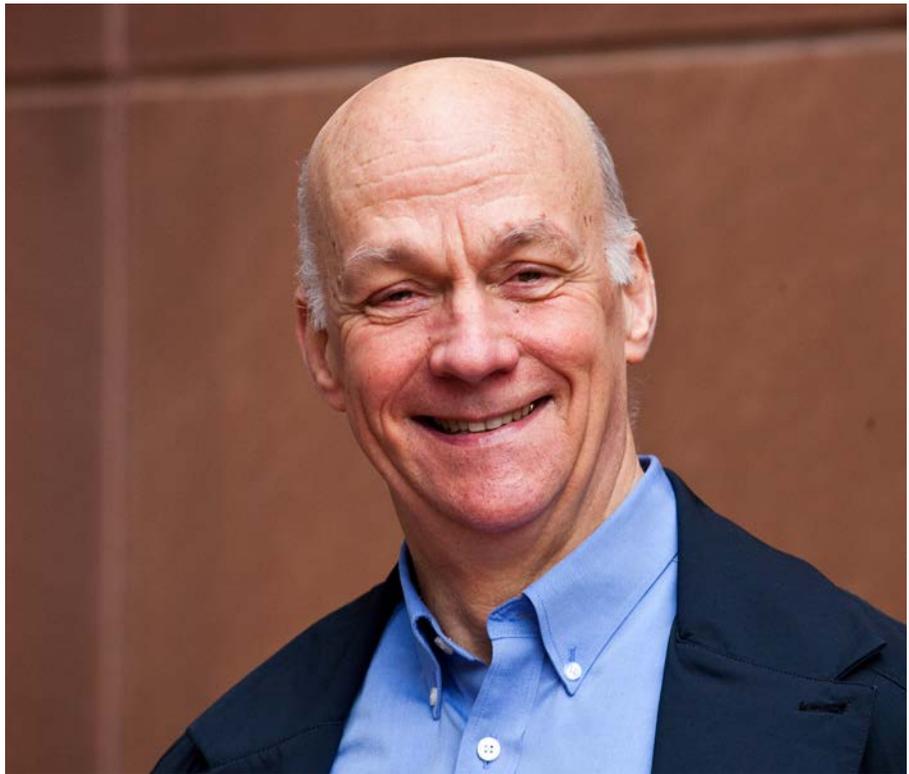
From launching satellites to improve our understanding of what we’re doing to the climate (and who’s doing it), to putting in place institutions for sharing information and resources, in any scenario, implementation of the Paris Agreement will be the work of decades.

“This is part of a long process of humanity trying to come to terms with the fact that it is radically restructuring the environment it lives in, and in turn being restructured by those changes,” Clark observes. “The comings and goings of one politician or another can help a little or hurt a little, but it’s the accumulation of efforts that is what gives us the direction and velocity of these things.”

Freeman advises a similarly big picture perspective. “Aside from war, this is the hardest thing the world community has ever done,” says Freeman. “We’re talking about changing the global energy system in under a century. Not surprisingly, it’s incredibly hard.”

Meanwhile, recent temperature trends offer a sobering reminder of the challenge we’re up against. The warmest year on record was 2015; 2016 is on track to destroy that record.

Even as the global community works to preserve a sense of urgency about bending the emissions curve down sharply, Clark emphasizes the need to keep this sense of the “long



game” in mind. There will inevitably be pitfalls, wrong turns, and delays. Even in the best-case scenario, in which Paris leads to the hoped-for ratcheting of ambition among all nations, Clark warns that we will need to brace for hard times to come.

“Our colleague John Holdren has argued in his role as President Obama’s science advisor that the path ahead will inevitably include a mix of ‘mitigation, adaptation, and suffering.’ The best we can hope for is to limit the suffering. We have enough commitment to warming of the earth system already in place that we’re going to take major hits,” he says. Those least responsible for causing climate change, he adds, are going to suffer the most. For all of its strengths, Paris doesn’t begin to address how to allocate resources in the global “triage mode” that we will likely face, and it offers no guarantees that we will succeed. Its provisions for helping the hardest hit communities adapt to coming changes are just one of many that will require further negotiations. But Paris does increase the odds that we will tip the scales in our collective favor, toward more mitigation and adaptation and less suffering.

The next step on the long journey from Paris took place when leaders

William Clark, Brooks Professor of International Science, Public Policy, and Human Development at the Harvard Kennedy School.

from more than 150 countries—including the U.S., China, and India—gathered at a signing ceremony at the United Nations in New York on April 22. That’s Earth Day. It was a symbolic gesture, of course. Emissions continued to rise that day, and will continue for many days to come.

But the solidified sense of global solidarity on display that day might, in fact, be the most important outcome of Paris. The agreement has codified the understanding that all nations—both those most responsible for changing our shared climate, and those least responsible but most vulnerable to the effects—must find common cause, and walk the path ahead, together.

A new sense of solidarity, a gamble on the power of peer pressure, a hope in deferred collective ambition—these may seem like shaky footing on which to base humanity’s future prospects. But looking back from the future, this breakthrough in Paris may seem a bigger step forward on the path to maintaining a stable, livable climate than we can even realize today. 🌍

Healthy Planet, Healthy People

HUCE hosts new initiative on “planetary health”

The effects of human activity on the planet go far beyond climate change, say Harvard scientists studying links between human health and the environment. In fact, the role of humans in altering a myriad of natural systems has the potential to halt or even reverse a series of dramatic health gains made in the past half-century.

To better understand the complex picture of what is happening—and respond to it—researchers across disciplines within and outside the University have launched an effort to unite and support scientists working at the intersection of the environment and health.

The Planetary Health Alliance (PHA) was formed this past January in partnership with the Wildlife Conservation Society (WCS) and supported by two grants from the Rockefeller Foundation, one to Harvard, of \$3.91 million over three years, and one to WCS.

“Increasingly, we have come to recognize that the health of humanity depends on ensuring the health and resilience of our

as Associate Director.

“The human transformation of most of Earth’s natural systems represents a clear and present danger to global health. There’s an enormous amount that can be done to address these threats—that’s why it’s important that we recognize these issues and devote research time and resources to them,” said Myers.

HUCE will house the PHA and the Chan School will participate jointly in the project.

Center Director Daniel Schrag said the interdisciplinary nature of planetary health makes the Center a good home.

“I believe these problems are important,” said Schrag. “I also really believe that, because of the community we’ve built, there’s almost a unique opportunity to get extraordinary teams of experts working on these issues.”

The study of links between environment and health is nothing new to Myers and Golden. Myers is investigating the health effects of pollution in Southeast Asia caused by humans burning forests to clear land for oil palm plantations. He has also examined how global pollinator declines may impact human health, as well as climate change’s impact on the nutritional value of

“We are already seeing suffering due to global environmental change. How much suffering happens is up to us.”

crops, discovering that higher carbon dioxide levels can reduce iron, zinc, and protein content.

Golden, meanwhile, has trained his eye on the reduced availability of wild foods in Madagascar, finding that it causes declines in diet quality and increases risks of micronutrient deficiencies. He is also leading an effort with Myers to explore how environment-related changes in the status of global fisheries are likely to affect nutrition and health.

Organizers plan to develop the Planetary Health Alliance into a consortium of universities, non-governmental organizations, and other partners. In only two months, over thirty influential institutions have joined the Alliance including The Lancet, the Institut Pasteur, Columbia University’s Climate and Health Program, the United Nations Foundation, and the University of Sao Paulo in Brazil. The alliance will support the planetary health community in a variety of ways. At Harvard, it will support a new course on the subject and create a postdoctoral and undergraduate fellowship program. It will also develop an online educational platform to include film, slides, and course syllabi.

To foster a broad community, leaders plan monthly e-updates on new research, an online journal club, and an annual meeting of the planetary health community.

“The idea is to grow capacity here, to use Harvard’s convening power to create an intellectual community ... to create excitement for people currently working in this space,” Schrag said.

Alliance fellows will work across a range of topics, including the impact of environment change on diet and nutrition, changes to disease ecology, human displacement and migration, waterborne illnesses, and mental health.

“We are already seeing suffering due to global environmental change,” Myers said. “How much suffering happens is up to us.”

—By Alvin Powell, courtesy of the Harvard Gazette



ALEX GRISWOLD

PHA group members, L to R: Christopher Golden, Associate Director; Samuel Myers, Director; Sarah Guth, Program Coordinator; and Amalia Aruda Almada, Senior Program Manager.

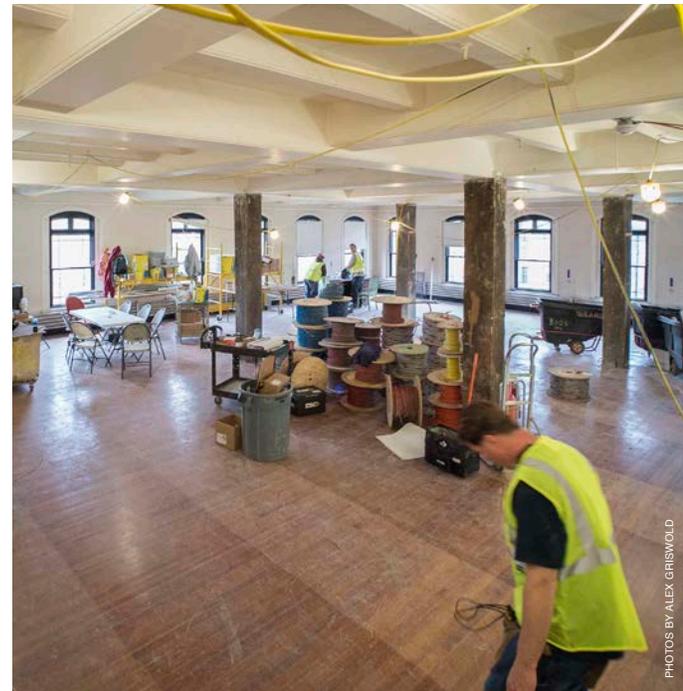
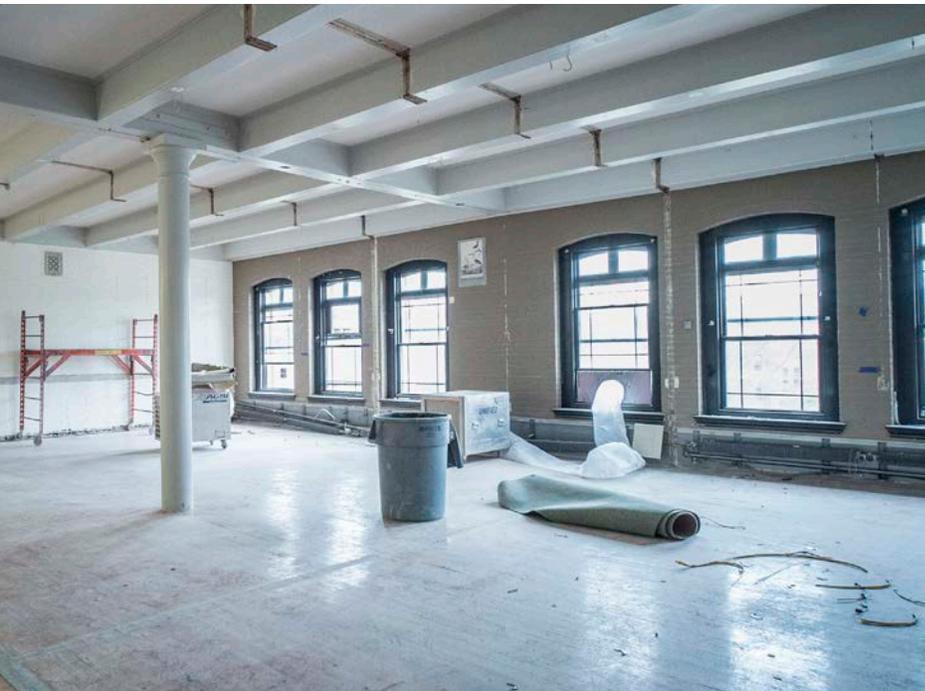
planet—from our climate, to our forests, to the air we breathe and the water we drink,” said Michael Myers, Managing Director at the Rockefeller Foundation. “The Rockefeller Foundation helped to pioneer the field of public health more than 100 years ago, and we are proud to support the field-building efforts of the new Planetary Health Alliance—which we think of as building ‘public health 2.0.’”

Samuel Myers, Senior Research Scientist at the Harvard T.H. Chan School of Public Health, will direct the project. Harvard Chan School Research Scientist Christopher Golden will serve



HUCE's New Home

This August 2016, HUCE will move to the other side of the Museum complex to newly renovated space that will be roughly three times larger. The Center will occupy the northwestern corner of the building—highlighted in green in the image above—adjoining the Museum of Natural History and the Museum of Comparative Zoology. The move will mean more seminar rooms and gathering spaces, new space for program activities, offices for short- and medium-term visitors, and space for a variety of research staff including graduate students and postdocs. Please come and visit us in our new space this fall! 🏡



Whither Solar Power?

A wander through the sunlit wilderness of policy, problems, and possibility

By Alvin Powell

If you're in solar power these days, business is booming.

Installations are up globally and even here, in the climate-politicized United States, solar power has shown a dramatic rise, with 2016 expected to be the best year for solar installations ever. In fact, if all 9.5 gigawatts of expected utility-scale solar are added, it will cross an encouraging threshold: the first time that solar has topped the list of new U.S. energy installations.

Solar advocates believe this is just the beginning and hope the trend will accelerate, driven in part by a dramatic decline in solar panel prices—some 80 percent over the last five or six years—and also by a new international commitment to address climate change, itself fueled by recent low-carbon commitments by the world's two largest greenhouse gas emitters, the U.S. and China.

But some energy experts say “Not so

fast,” and describe today's enthusiasm around solar as akin to yesteryear's “irrational exuberance” around stocks: a bubble destined to pop. While prices for solar panels have indeed fallen dramatically, they haven't fallen nearly enough to compete with fossil fuels, they say, and government attempts to push solar onto the electricity market through an array of subsidies, tax breaks, and favorable electricity pricing are ultimately doomed to fail.

In fact, they say, early strains are already appearing where renewable penetration is high, including countries like Germany, whose renewable energy economy has high wind and solar, high residential electricity prices, and, paradoxically, carbon dioxide emissions that, after years of decline, have begun to rise.

Similar strains can be seen elsewhere, they argue, including here in the U.S., where renewable penetration is rising

and sometimes doing strange things to electricity prices—driving them close to zero and even negative—and setting us on a path that could ultimately lead to utility company bankruptcies. U.S. utility companies, meanwhile, aren't waiting until they have to hire bankruptcy lawyers. They're pushing back hard at the state level against policies designed to encourage small-scale, rooftop solar power, and having some success. They've added fees for solar customers in Nevada and Arizona that have raised costs and forced solar installers to lay off workers and curtail operations. These rollbacks are occurring in the very places whose ample sunshine makes them ideal for this kind of power generation.

Solar's problems are not just ones of cost, a point on which both advocates and detractors agree. Solar is not a 24/7 power supply, leaving other sources to fill in gaps when the sun doesn't shine. It's also most

June U.S. Solar Generation, 2005-2015

Graph courtesy U.S. Energy Information Administration



gigawatthours

3,000

■ Solar photovoltaic

■ Solar thermal

2,500

2,000

1,500

1,000

500

0

June 2005 June 2006 June 2007 June 2008 June 2009 June 2010 June 2011 June 2012 June 2013 June 2014 June 2015

efficiently generated in sunny places like Arizona, Nevada, and other states of the American desert Southwest, far from the nation's biggest population centers.

A global boom

Despite the debate over solar's future, there is little debate that solar power has come a long way. From an energy afterthought little more than a decade ago, solar today is one of the world's fastest-growing sources of electricity—a trend that forecasts expect to continue.

The International Energy Agency, in its "Medium-Term Renewable Energy Market Report," said that in 2014 renewable power—largely wind and solar—represented over 45 percent of additions to the global energy supply, measured by gigawatts of capacity, though the percentage of actual power generated is far lower due to the intermittency of renewables. By 2020, the IEA expects renewables to account for two-thirds of new capacity additions globally, with solar the second-largest source after wind. These are expected to make up nearly all new energy installations in the world's richest countries, those among the Organization for Economic Cooperation and Development (OECD). In addition, three countries—China, India, and Brazil—are expected to account for two-thirds of new renewables installations.

A November 2015 report by consulting firm KPMG, meanwhile, says that solar power in India is poised for growth potentially rapid enough to disrupt the energy market there. The report, titled "The Rising Sun: Disruption on the Horizon," contends that solar power may have reached the point where it is competitive with coal-generated electricity, with solar power prices within 15 percent of coal and they expect solar prices up to 10 percent lower than coal by 2020. The report acknowledges, however, that estimates "may not fully capture" costs of integrating solar into the grid to provide on-demand capacity from coal plants, energy storage devices or redistribution by transmission from areas where the sun is still shining.

Forcing solar onto the market through subsidies, tax credits, and favorable pricing common today will cause unintended consequences that twist the electric market into knots, potentially driving utility companies bankrupt.



In the United States, the record 9.5 gigawatts of new utility-scale solar expected in 2016 tops the 9.4 gigawatts installed over the prior three years, but may have something to do with a rush to completion before the 30 percent federal Solar Investment Tax Credit is set to expire at the end of the year. Recent federal action extended the credit through 2019.

The Solar Energy Industries Association projected that the tax credit extension will result in an additional 72 gigawatts of solar photovoltaic installations through 2020, and that by then solar will provide 3.5 percent of U.S. electricity generation, up 3,000 percent from 2010, when solar provided just 0.1 percent. By then, the industry expects to be adding 20 gigawatts of capacity annually, equal to the total installed solar that existed in America as recently as 2014.

Reality check for the solar industry

William Hogan is the Plank Professor of Global Energy Economy at the Harvard Kennedy School (HKS) and Harvard's resident expert on the electric grid—and his message might be hard to hear for those who view solar's apparent suc-

William Hogan, Plank Professor of Global Energy Economy at the Harvard Kennedy School.

cess as good news and a positive step in addressing the global threat of climate change. Solar's problem, Hogan says, is fairly simple: it's too expensive. Forcing it onto the market through the subsidies, tax credits, and favorable pricing common today will cause unintended consequences that twist the electric market into knots, potentially driving utility companies bankrupt.

"It is true that costs have come way down, but there's a strong argument [that it's] not enough and it's still too expensive," Hogan said. "The countervailing view is it's reduced the cost of renewables and they're now competitive in the market. You'll see that in a lot of places. But there's usually a caveat to make."

Statistics showing solar to be competitive with other sources typically have one of three problems, Hogan said. First, they might be cherry-picked, numbers from places with the most ideal conditions to generate power, while ignoring additional costs like transmission or those due to intermittency, costs which have to be paid in the real world. Second, he said, is the problem of dumping. The Chinese, who are one of the world's largest manufacturers of solar panels, have overbuilt capacity and are selling panels below cost, which has not only prompted accusations of undercutting other nations' solar manufacturing industries, it's also artificially

lowered prices.

Third, he said, are the subsidies: the investment tax credits to get plants built and guaranteed higher prices for power once they're running. These supports artificially lower costs and insulate solar plants from the market.

"That makes it confusing when people say we have these fantastic opportuni-

"There's an adage in solar power: 'We put up panels where the subsidies are, not where the sun is.' You see a lot of solar in Germany, where it is not sunny, and a lot in Massachusetts. We live here, we know it's not sunny."

ties," Hogan said. "This is not sustainable. It's a bubble, we haven't turned the corner for the future."

Solar is expensive enough that Hogan believes the industry's biggest challenges are not ones of marketing and deployment, as current policy design would indicate. Rather they are of research and development. Solar, in effect, needs to go back to the drawing board.

"I think the basic story is we've done enormous things to improve the economics of renewables—not enough—but enormous things," Hogan said. "We shouldn't give up hope that we can innovate and improve it enough, but it is an R&D problem, not a financing and deployment problem. We're spending a lot of money to use the technology we currently have, spending too much money."

Figures from the most recent U.S. Annual Energy Outlook, released in April 2015, predicts that in 2020, solar power

will still be significantly more expensive than that from other sources. Solar's "leveled cost of electricity"—considered a good statistic by which to compare power from different sources—is projected at \$125.3 per megawatt hour compared with \$95.1 per megawatt hour for coal, \$75.2 for conventional natural gas, and \$73.6 for wind.

It is subsidies, however, not cost, that determines what gets built and what doesn't. The subsidy with the largest impact in this country is a 30 percent solar investment tax credit, which has just been extended through 2019. After that, it will fall to 26 percent in 2020, 22 percent in 2021 and then to 10 percent in 2022 and beyond for commercial installations. It is eliminated entirely after that date for residential solar installations.

"There's an adage in solar power: 'We put up panels where the subsidies are, not where the sun is,'" said Associate Professor of Public Policy Joseph Aldy. "You see a lot of solar in Germany, where it's not sunny, and a lot in Massachusetts. We live here, we know it's not sunny."

In addition to that generous tax credit, Aldy said that U.S. solar facilities can utilize accelerated depreciation worth another 10 percent of the cost, and qualify for additional state credits to meet

renewable power mandates.

Aldy said it's clear investors believe that solar's future is in large, utility-scale installations, where there's more potential to compete should subsidies be lowered or eliminated and a price on carbon levied. Today's investors however, are attracted by the sizeable tax credits bundled in long term power purchase agreements that lock in a price for electricity.

"From an investor's standpoint, that's removing one element of risk or uncertainty to the returns," Aldy said. "There's a question of whether there are ways to do financing of solar in a future market with a carbon price."

Distributed solar, the small-scale installations whose panels dot your neighbor's house and the roofs of some local businesses, can also take advantage of "net metering," an increasingly controversial requirement for utilities to pay small-scale solar generators the same retail rate for power that the utility itself charges customers. Utilities complain that the policy effectively exempts residential solar customers from paying the distribution charge other customers pay, which approaches 50 percent of a typical bill. That means solar customers are not paying for a distribution system they are nonetheless still dependent upon for power when the panels aren't producing.

"It's worth 35 percent of what we're paying for it. As a country, it seems to me that's a problem," Hogan said of rooftop solar. "I like the old aphorism. If you're willing to spend enough money, you can make anything look cheap."

Such small scale solar installations that can take advantage of net metering have been rising rapidly, according to EIA figures, increasing from about 1 gigawatt installed in 2011 to 2.2 gigawatts in 2015. That popularity may be why the battle over rooftop solar isn't going away. While utility companies have been successful at putting additional fees on customers' bills in some states, the solar industry is engaging customers in fighting back, including a ballot initiative in Arizona that would put a right to net metering in the state constitution.

Still, Hogan believes that the money spent on tax breaks and expensive power would be better spent on research



Joseph Aldy, Associate Professor of Public Policy at the Harvard Kennedy School.

Michael McElroy, Butler Professor of Environmental Studies and Chair of the Harvard China Project.

for a breakthrough solar technology that is truly cheaper than fossil fuels, even if it means waiting a decade to deploy new solar.

But Hogan also cautions that there's no guarantee that research would be successful, and in any case will likely depend on the politically-difficult implementation of a carbon tax that would make coal and natural gas—which each generate about a third of U.S. electricity today—more expensive.

"The question is how long should you wait [to redeploy solar]. My calculation, to a first approximation is that if you don't have a CO₂ tax, you never make it," Hogan said. "You should wait forever because it never gets cheap enough. With a CO₂ tax you should wait a decade or more. So even with a CO₂ tax it's too early to deploy the technology we have now."

Hogan bases that conclusion on figures from the U.S. Department of Energy that indicate that, even with a carbon tax, the cost of electricity generated by current solar technology "isn't even in the ballpark" of that generated by other sources.

"This is considered to be extremely bad news," Hogan said, "but I think that's what underlies the factual situation."

Solar's current success, Hogan said, has come in part because it's still small enough that the grid can absorb it without significant negative impacts.

"It's destined to fail. That's what I think. It takes a while, as soon as it gets to be large enough, then it'll fail," Hogan said. "When it's small, who cares?"

Strains in Germany

Some nations that have rapidly increased their reliance on solar have seen their energy systems struggle or dealt with unintended consequences from government subsidies. Spain, Hogan said, guaranteed solar generators a high price for energy through a "feed in tariff" but borrowed instead of passing the higher prices on to consumers. The result, Hogan said, is an accumulated debt that totals the cost of an entire year's electricity—they'd have to double rates to pay it off—and a national pullback from solar power.

"They said, 'No mas, we're not doing this again. This was a big mistake,'"



Hogan said.

China enacted similar guaranteed high prices for solar-generated electricity—which prompted a rush to build solar facilities in the sunniest, most ideal locations, according to Michael McElroy, Butler Professor of Environmental Studies and Chair of the Harvard China Project. The problem, McElroy said, was that wasn't necessarily where the people were. So Chinese officials added location requirements to the tariff to ensure the new solar goes in where the demand is.

Germany has had similar problems but, like China, has not wavered in its support for solar and wind power. Germany has been widely hailed as a renewable power success story, generating about 30 percent of its electricity annually from renewables, including wind, solar, and

hydro. While a significant portion of German electricity comes from clean renewables, coal—locally mined and cheaper than natural gas imported from Russia—has become the nation's next choice, a decision that actually increased carbon dioxide emissions in 2015.

"[Renewables] can be an expensive decision and you see it in the cost of the grid they maintain," said Joe Lasziter, Senior Fellow at Harvard Business School and retired Senator John Heinz Professor of Management Practice in Environmental Management. "You have to have a collection of different power generation assets ... that can deliver the hour-by-hour profile of power that consumers and industry need in summer and quite a different profile in winter. That results in a lot of capacity idling—

Solar's current success, Hogan said, has come in part because it's still small enough that the grid can absorb it without significant negative impacts. "It's destined to fail. It takes a while, as soon as it gets to be large enough, then it'll fail. When it's small, who cares?"

hydro. To foster renewables, the nation requires renewable power to be used on the grid first and has a feed in tariff that guarantees high prices, which are passed on to residential customers. The country has also raised the stakes on its renewable power bet, by deciding to close its nuclear plants by 2022.

Recent headlines, however, have hinted that beneath the nation's apparent success in fostering renewables, there

typically much of that capacity can't be throttled up and down quickly—making it remarkably inefficient, remarkably high-polluting."

But Aldy said Germany's rising carbon dioxide emissions result not from subsidies alone, but from the interplay of the German renewable incentive system with the European Union's cap-and-trade emissions trading scheme, of which they're part. Germany's aggres-

FACULTY PROFILE

Joyce Chaplin



PHOTO COURTESY JOYCE CHAPLIN

Everyone who has ever lived, says Joyce Chaplin, has done so in the natural world. It should follow, then, that all historians operate with the environment in mind, no matter the period or place they are studying. “If I have any criticism of academic history, it is how environmental history is segmented off,” says Chaplin, the Phillips Professor of Early American History. “Certainly for undergraduates especially, every survey course should include something about the environment without necessarily saying, ‘And this is the environmental history part of the course.’ No, it’s just part of the past.”

Should she want to describe herself as an environmental historian, she would have the bona fides. Her path to academia started with an interest in the Green Revolution’s potential as a salve to world hunger, which led to an interest in agriculture and then to the history of both agriculture and the environment. “How people lived in a past time when they had an awareness of nature, including of finite resources, and then how we have developed the natural world away from those assumptions, seem to me to be central,” says Chaplin. As a graduate student, she continued work that began with an undergraduate thesis on rice cultivation in South Carolina, expanding it to look at agricultural improvement in South Carolina, Georgia, and British East Florida—examining both the socioeconomic history of the crop choice and production as well as the intellectual impact of the Enlightenment.

Of late, Chaplin has developed a focus on the field of food history, including culinary history.

“It is really the history of food prepared according to cultural norms of what a meal or cuisine should be,” says Chaplin. She recently co-edited a series of essays on food history and co-wrote (with Alison Bashford from the University of Cambridge) a book on English philosopher Thomas Robert Malthus that examines how food supply influenced his views on population growth. Last year, she began teaching an undergraduate course on American food in a global context. She taught the course again this year with the subtitle “How Did The Past Taste?” Each week has offered students a new edible sample. “And they’re not always intended to be pleasant,” Chaplin says with a laugh. One lesson includes offerings of both Graham Bread, the “original health food” prepared by nineteenth-century food reformer and purveyor Sylvester Graham, and its sweeter, modern descendant, Graham crackers. “Food is an element of culture, and culture varies over time. To understand food and understand how people respond to food, you need to recreate the context around it.”

Food also allows the students a more personal interaction with the material. “There is this new sensory history—how did the past sound, how did it smell, how did it feel,” says Chaplin. “I’m looking at how did it taste and what does that mean about what it meant to be human in the past, what it meant to experience pleasure—how hungry did you have to be to eat this,” she says. “It is recreating a level of experience about the past above and beyond what we can read or see about it.”

— Dan Morrell

sive renewables policy has flooded the market with clean power that lowers demand for carbon dioxide emissions allowances. That lowers their price and makes the cost to emit carbon dioxide so low that it makes financial sense to burn dirty coal instead of cleaner and more expensive natural gas.

The principle that underlies cap-and-trade is that regulators don’t—and can’t—have as much information as that held by hundreds or thousands of individual companies, Aldy said. A cap-and-trade system sets an overall limit on how much can be emitted, sets an allowance price for emissions under that cap, and then steps aside and lets ingenuity go to work. Companies that can figure out how to emit less CO₂ can sell their emissions allowances to companies that still need them, and that financial incentive drives the system to lower and lower emissions. Telling companies how the cuts have to be achieved—through a strong renewables policy—changes the incentives, sometimes in unpredictable ways.

“As soon as you say you have to do so much wind and solar, it’s contrary to the fundamental logic of market-based approaches like cap-and-trade or an emissions tax,” Aldy said. “It’s not going to do anything for the environment.”

That same dynamic could emerge in the United States, Aldy said, in places like California, which has both a cap-and-trade system and a state renewable portfolio, and in the Northeast, where Aldy described the regional greenhouse gas initiative as effectively a “power sector CO₂ cap-and-trade” system, and where each state also has renewable power portfolio standards requiring a certain percentage of power from renewable sources.

Policy growing pains

Where some see fundamental flaws, however, others see growing pains, all part of the process of bringing a society’s changing values alive through shifting public policy and of figuring out how to integrate a new energy source into an aging system.

“They’re meeting their renewable energy targets and doing it without [significant] public pushback on the system,” said McElroy, who expressed confidence Germany would eventually

“I want to see a high-energy, high-wealth society ... As far as I can tell, only two technologies can plausibly scale to do something like that without an environmental holocaust: nuclear and solar.”

adjust policies to counter whatever forces are pushing emissions upward.

Henry Lee, Jaidah Family Director of Harvard’s Environment and Natural Resources Program and Senior Lecturer in Public Policy at HKS, said what’s happening with solar today has happened with other resources and in other contexts before. Policies that go awry will eventually get fixed, Lee said, which is part of the reason subsidies are temporary. If the public pushes back, they’ll get adjusted, here or abroad.

In the meantime, Lee and McElroy said, the German solar industry is benefitting from both economies of scale and from the learning and innovation occurring in production, distribution, and installation. Because of these processes, McElroy said, solar panel installation costs about half in Germany what it costs here. That’s something McElroy knows from personal experience. He recently had solar panels put on his home at a cost of about \$5.20 a watt, compared to \$2.60 a watt in Germany.

More efficient solar panels are also in the offing, Lee said. Those sold today are typically 15 to 16 percent efficient, but 20 percent efficient panels are in the lab and will eventually make their way onto the market. Though less concerned about market effects of current subsidies, Lee agreed that the ultimate goal is for low-carbon, low-cost power to “become market competitive,” something he believes that subsidies alone can’t effect.

“I can subsidize my way to a small per-

Top: Joseph Lassiter, Senior Fellow at Harvard Business School and retired Senator John Heinz Professor of Management Practice in Environmental Management. Bottom: Henry Lee, Jaidah Family Director of Harvard’s Environment and Natural Resources Program and Senior Lecturer in Public Policy.

centage of renewables, but if I want it to take off, I have to make it cost-competitive because the government can only force this so much,” Lee said.

David Keith, McKay Professor of Applied Physics and Professor of Public Policy, however, expressed skepticism that the goal for solar power ought to be to make it price competitive with fossil fuels. Rather, he said, the goal is a cleaner environment.

Government regulation of environmental damage is nothing new and often has imposed new costs on society, he said. It happened with the Clean Air Act, the Clean Water Act, in banning leaded gasoline, and in changing the chemical coolants in refrigerators and air conditioners to prevent ozone depletion. Those all raised costs but were done anyway in order to protect the public.

“We have solved lots of environmental problems before by hard laws and not just because things have gotten cheaper,” Keith said. “I actually want to protect people’s lives, and I think it’s worth paying something for environmental protections.”

That doesn’t mean that there isn’t a need to innovate and lower costs, Keith said. A low carbon world, he said, should also be a high-energy world, one that provides ample energy to developing as

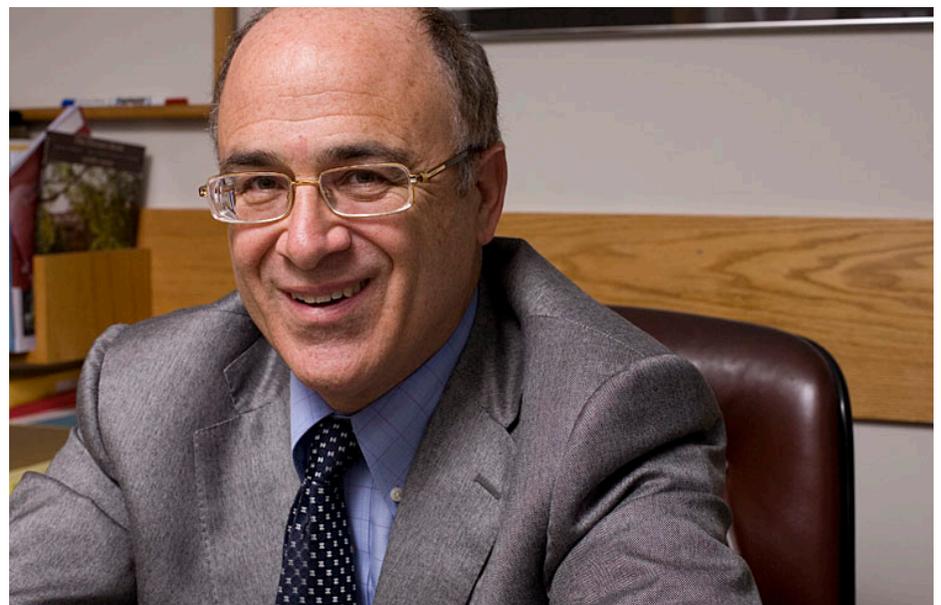


well as developed nations.

“I want to see a high-energy, high-wealth society,” Keith said. “As far as I can tell, only two technologies can plausibly scale to do something like that without an environmental holocaust: nuclear and solar.”

Technical hurdles

Whether or not solar ever becomes price-competitive with fossil fuels, the fact that solar systems only generate power when the sun shines remains a significant problem. This intermittency affects both its integration into the current grid and its prospects of becoming the foundation of



a future low-carbon, low-fossil fuel grid. Experts offered two potential solutions, one lower tech but fraught with political problems and the other high tech and still being developed.

The low-tech solution involves building robust, long-distance power transmission lines, allowing electricity generated where conditions are most favorable to be moved to places where it is most needed. That would enable solar power generated in America's sunny Southwest—or wind power in its windy Midwest, for that matter—to light the night in Chicago or even the cloudy cities of the Northeast. If the lines crossed multiple time zones, they could help even out peaks and valleys in demand in different parts of the country.

Transmission would only be a partial solution, however, as night eventually falls across the entire country. In addition, it has political problems, Aldy said. People living in between, whose commu-

Developing a battery large enough to be useful at a grid scale, at a cost that the public might be willing to pay, has been a challenge ... [however,] a Harvard team has hit on a combination they think might do the trick.

power and instead typically match supply and demand hour by hour, day by day.

A relatively new type of solar plant incorporates storage into its design. Instead of the more familiar solar photovoltaic design, in which photovoltaic cells convert sunlight to electricity, solar thermal plants use an array of mirrors to concentrate solar energy onto a central structure where the heat generates steam that turns a turbine. A variation on this design, in use at the Crescent Dunes solar energy plant in Nevada, can also store heat in molten salt, which can be used to generate power when the sun doesn't shine. Though it offers the promise of addressing solar's intermittency,

a concentrating solar plant makes the cost problem worse. The Energy Information Administration projects a levelized cost of electricity of 21 cents per kilowatt hour by 2020, almost double that of photovoltaics.

"Some of these technologies are quite promising, but really first of a kind," Aldy said. "It's not, 'Can I put up the same

panels on your house as two years ago but now they're cheaper to manufacture.' It's bringing to commercial scale a new technology. There's going to be learning opportunities."

Battery storage is another option, but developing a battery large enough to be useful at a grid scale, at a cost that the public might be willing to pay, has been a challenge.

"It's not like people aren't trying everywhere. A lot of money has been spent and progress is very, very slow," Lassiter said.

A Harvard team has hit on a combination they think might do the trick. A

3-kilowatt demonstration battery based on their technology is being developed by a Connecticut company and is expected to be ready within a year, at which point they'll have a better idea of how much it'll cost.

The team, including Michael Aziz, the Sykes Professor of Materials and Energy Technologies, Roy Gordon, the Dudley Cabot Professor of Chemistry and Professor of Materials Science, Theodore Betley, Professor of Chemistry and Chemical Biology, and Alán Aspuru-Guzik, Professor of Chemistry and Chemical Biology, has devised what is called a "flow battery" that they believe has the potential to be just such a grid-sized storage device.

Storage in familiar solid lithium-ion batteries is currently too cumbersome and expensive to deploy on a large scale, Aziz said. A recent entrant into the market, Tesla's Powerwall battery, costs about \$350 per kilowatt hour of energy capacity, three times the potential cost of the developing flow battery.

"Lithium will come down too," Aziz said. "The \$64,000 question is can lithium come down by a factor of three. Most people I talk to doubt it, but Elon Musk might have a different opinion."

The average retail price of electricity in the U.S. is 10 to 12 cents per kilowatt-hour. To be commercially viable, Aziz said, the added cost for storage cannot be more than another couple of cents. The demonstration battery being built now will help them better understand costs, but Aziz said they may come in under about 2 cents per kilowatt hour. "If it ends up costing \$120 per kilowatt hour when it's at mass production scale, and the useful life of the battery is 10,000 cycles, say one cycle per day for 27 years, then for \$120 you've put 10,000 kilowatt hours into your battery and taken them out again. That comes down to 1.2 cents per kilowatt hour, before you raise it a bit for efficiency losses."

"The low cost and high performance of our energy-storage chemicals gives us a fighting chance of reaching these targets, but I can't say we're there yet," Aziz



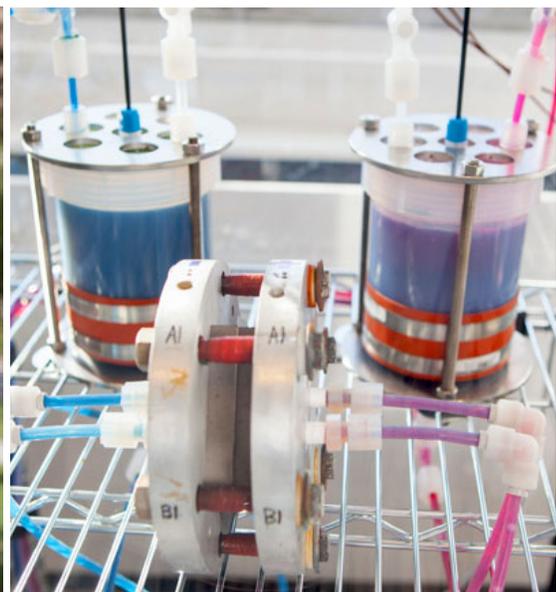
PHOTO COURTESY DAVID KEITH

David Keith, McKay Professor of Applied Physics and Professor of Public Policy.

nities and properties the new transmission lines would cross but who would get no real benefit, don't want them.

"If you're in Iowa or Minnesota, you don't want to pay for the line bringing wind power from South Dakota to Chicago," Aldy said.

The second potential solution would be to store solar or wind power generated when conditions are favorable so it can be used when demand is highest. Operators of today's grid have few ways to store



ELIZA GRINNELL / SEAS COMMUNICATIONS

said. “It will take building and testing at larger scale.”

The concept of the flow battery has been around since the 1970s, but finding the right liquid chemicals that can provide utility-scale storage at a cheap price has been a challenge. Flow batteries are on the market now for special applications, using vanadium ions—which Aziz described as “rare and expensive”—as a key component.

The Harvard team screened over a million molecules, and created a battery with quinones—an inexpensive organic molecule made of earth-abundant elements—on one side, and ferrocyanide—an inexpensive food additive—on the other. These chemicals are dissolved in water and flow from the positive and negative tanks to interact at the electrode, sending electrons into the circuit. The depleted chemicals then cycle back to the tank, ready to be recharged when surplus power is generated.

Though the Harvard team put an emphasis on finding non-toxic, non-corrosive components, the biggest advantage of a flow battery is scalability, Aziz said. If a lot of storage is needed, you don’t need to add a lot of complex technology or extra expensive electrodes, just bigger tanks to hold more chemicals.

“If you need more energy for a given power, instead of stacking banks and banks of batteries with more electrodes that you don’t need, with a flow battery you just get big dumb tanks,” Aziz said. “The goal is sufficiently safe, inexpensive and scalable storage to make intermittent renewables dispatchable.”

Another possible solution to solar’s intermittency problem may one day be sitting in our driveways, McElroy said. Today, tail-pipe emissions are a big part of the carbon problem and electric vehicles a potential solution. If, over the next 20 years in the U.S., 110 million of the 230 million cars are electric, all of their batteries plugged in in garages across the country would represent a huge amount of storage potential.

McElroy described a scenario where plugged in cars charge at night when demand and prices are low. During peak hours, cars not being driven could reverse the flow and supply electricity to the grid, helping even out demand.

“That’s a big, big deal,” McElroy said. “I think that’s a smart way to go.”

Though work remains to be done, the fact that these problems are being taken seriously—not just by scientists, but by society at large—represents a sea change in attitude that is largely attributable to the steep decline in the cost of solar power, according to Daniel Schrag, Director of the Harvard University Center for the Environment, Hooper Professor of Geology and Professor of Environmental Science and Engineering.

“Whatever the strategy you choose to manage the intermittency of solar, cheap solar is getting many locations close to the point of creating the markets for those solutions, which never existed before,” Schrag said.

That effect is important even though solar power still isn’t cheap enough to transform the global power system, Schrag said. The price decline, combined with subsidies, is driving an installation

Michael Aziz, Sykes Professor of Materials and Energy Technologies; A prototype flow battery in the Aziz lab.

boom that has forced utilities, customers, and regulators to sit up and take notice of a technology that not too long ago was easy to ignore. There may be management issues in Germany, California, and elsewhere that point out needed policy reform, but it is encouraging nonetheless that the discussion is beginning to happen, according to Schrag.

“Policies and the way people bill will be rethought. In some ways, that’s what’s great about cheap solar because it’s driving that,” Schrag said. “Ten years ago we didn’t think we’d get close to that anytime soon, and now we’re pushing that in a number of locations, with wind in Iowa, sun in California.”

A future grid

For those wondering what the grid of tomorrow might look like, 2016’s anticipated installations might provide a preview, at least if subsidies continue. Renewable sources will make up more than 60 percent of new capacity, with wind’s 6.8 gigawatts joining solar’s 9.5. Throw in another 1.1 gigawatts from the country’s first new nuclear plant in 20 years—the Tennessee Valley Authority’s Watts Bar 2 plant in Tennessee—and two thirds of 2016’s new capacity is expected to come from low-carbon sources.

Fossil fuels, however, haven’t gone away, and the flip side of the dramatic decline in solar panel prices has been an equally dramatic decline in natural

gas prices. Any future grid, experts said, is likely to have significant power generation from natural gas, which can be ramped up and down to backstop renewables' intermittency. In 2016, about 8 gigawatts of natural gas is expected to be added though the year will see almost no new coal. In fact, 2016 is expected to be the year that natural gas supplants coal as the dominant fuel source for U.S. electricity generation, with each providing about a third. Coal's trajectory is opposite that of natural gas and experts see coal making up less and less of America's electricity generating mix. Perhaps a sign of that is the fact that, in 2015, 80 percent of the 18 gigawatts in plant retirements were of coal plants, according to the Energy Information Administration.

A major factor in shaping the future grid, at least in the United States, will be whether the country adopts a price on carbon, either via cap-and-trade or a carbon tax. Though still considered politically difficult, such a move would make fossil fuels more expensive—though natural gas would likely remain competitive—and renewables more competitive. It would help drive carbon out of the electricity system and likely be cheaper than subsidies to boot.

"Putting a cost on carbon is feasible, it's also a lot less expensive. It is this latter point that people don't understand," Lee said. "People don't see that they're paying for these subsidies, but they do see that they're paying for a price on carbon. Most every reputable study that I have seen says that it is far less expensive to put a tax or

price on carbon to reduce emissions than it is to try and reach the same reductions through regulation or subsidies."

The role of nuclear power in a future energy grid is a bit of a wild card, experts said. Some see nuclear as a preferable partner to renewables over fossil fuel-burning natural gas. Climate change concerns were actually beginning to soften no-nuke attitudes, Aldy said, until the disaster at Fukushima hardened them again.

The construction of new U.S. nuclear plants, however, has become so costly

"Most every reputable study that I have seen says that it is far less expensive to put a tax or price on carbon to reduce emissions than it is to try and reach the same reductions through regulation or subsidies."

and bound in regulation that it's unlikely many new plants will be added to the nation's energy mix. Installed nuclear, meanwhile, still supplies 19 percent of the U.S.' electricity and those plants' eventual retirement represents a potential climate setback if they're replaced by fossil fuel-burning plants.

Lassiter expressed some hope that new, safer and much cheaper nuclear designs will spark a renaissance of the industry, at least outside the U.S., in the 2020s; but,

in the U.S., a complete rethink of the regulatory process is needed that dramatically cuts the cost and the time required to license new nuclear designs if those designs are to be brought to market in the U.S. any time soon.

Lassiter and Keith also pointed out, however, that the energy future—clean or otherwise—is different in different places, each dealing with different climates, different natural resources, and different governments.

"There are different solutions depending on the local economics and the local politics in different parts of the world," Lassiter said. "Until you disaggregate, you get this uninteresting average. It's like putting vegetable soup in a puree machine, you get glop."

Germany's renewables policy, for example, is affected by its decision to eliminate nuclear power and its desire to limit reliance on Russian natural gas. That favors renewables and drives up costs, which so far the German people seem willing to pay.

The situation might be different in a poorer nation, Lassiter said. Absent the solar "disruption" predicted for India by KPMG, Lassiter expects that the developing world will continue to install coal plants to power the cities and factories that drive economic development while distributed solar microgrids have the prospect of leap-frogging to the rural areas, where people do not want to wait for the traditional power grid to be run out to them.

"Rich countries can do what they want," Lassiter said. "Poor countries will do what they must." 🌍

2016 Undergraduate Summer Research Award Winners

The Center's annual Undergraduate Summer Research Fund provides scholarships for students to complete research across a variety of disciplines. This year, the Center offered 14 assistantships for research with Harvard faculty and nine awards for independent research to undergraduate concentrators in Applied Mathematics, Chemistry, Chemistry & Physics, Environmental Science & Engineering, Environmental Science & Public Policy, Earth & Planetary Sciences, Government, Integrative Biology, Neurobiology, and Social

Studies. Summer research opportunities are made possible by the generous support of Bertram Cohn '47.

- **Melissa Balding** '17, "Urban Sustainability Lessons from Innovative Street Design in Portland, Oregon"
- **Ezekiel Benschirum** '19, will research hydraulic limits to carbohydrate transport in trees with Professor Noel Michele (Missy) Holbrook.
- **Govind Bindra** '18, "Low Cost Agricultural Diagnostics"

- **Brooke Bourgeois** '17, will partner with Professor Elizabeth Wolkovich to study "From Plant Traits to Winegrapes."
- **Juliet Bramante** '18, will research the efficiency, environmental, and fiscal implications of wind power policies with Professor Joseph Aldy.
- **Garrett Burk** '18, will work with Professor Peter Rogers on the project "Water Supply Conservation and Demand Management in the Water Scarce Countries of the Middle East."
- **Savannah Butler** '17, will explore "Isoprene Measurement and Instrument Design" under the guidance of Jim Anderson.
- **Eamon Corbett** '17, "Biogeography, Genetics, and Conservation of Birds in Northeastern Brazil"
- **Abby Duker** '18/19, will work with Professor

Secretary of State John Kerry Salutes New HUCE-Global Health Institute Partnership

A new partnership between HUCE and the Harvard Global Health Institute (HGHI) received warm words of encouragement from Secretary of State John Kerry, who addressed faculty affiliates from both programs at a reception at the Harvard Art Museums in May 2016. In his remarks to the group, Secretary Kerry reflected on the many connections between climate change—and environmental change more broadly—and human health impacts. Citing threats from extreme weather and sea level rise in the United States, to water scarcity in Africa, mercury in our oceans, and environmentally-induced asthma in children, Secretary Kerry praised the new initiative as “important in so many different ways.”

The leaders of this new partnership plan to bring both global health and environmental faculty together to develop academic programming and a research agenda that works to forge new connections between the two campus communities. HGHI Director Ashish Jha, Li Professor of International Health and Professor of Medicine, noted, “We have to be scientifically thoughtful about this. If you start making connections where there are none, you will lose credibility,” Jha said. “We have to be thoughtful about ... going only where the science and data allow us to go, but that said, the science



and data allow us to go much further than I think we have made clear.” HUCE has already made a substantial move in this direction with the launch of the Planetary Health Alliance, led by Samuel Myers and Christopher Golden, earlier in 2016 (see story on page 12).

In his remarks, HUCE Director Daniel Schrag highlighted the challenges of steering the attention of the global health community, focused on “acute” public health crises, to the longer-term threats that climate change will bring. “We’re talking about the future of the planet, and we’re talking about future generations. I

truly believe that future generations will look back at us and ask, ‘What were we doing? How could we possibly have made the decisions that we made?’” Schrag said. Jha agreed, warning, “If we don’t begin to work on it now, we’ll have missed an important window,” Jha said. “And I think this is what universities ought to be doing, thinking about the long run.”

Photos (clockwise from far right): Secretary of State John Kerry; John Kerry with HGHI Director Ashish Jha; HUCE Director Dan Schrag with Ashish Jha.

Ann Forsyth on “Health and Places Initiative: Looking back on the Healthy Cities Program.”

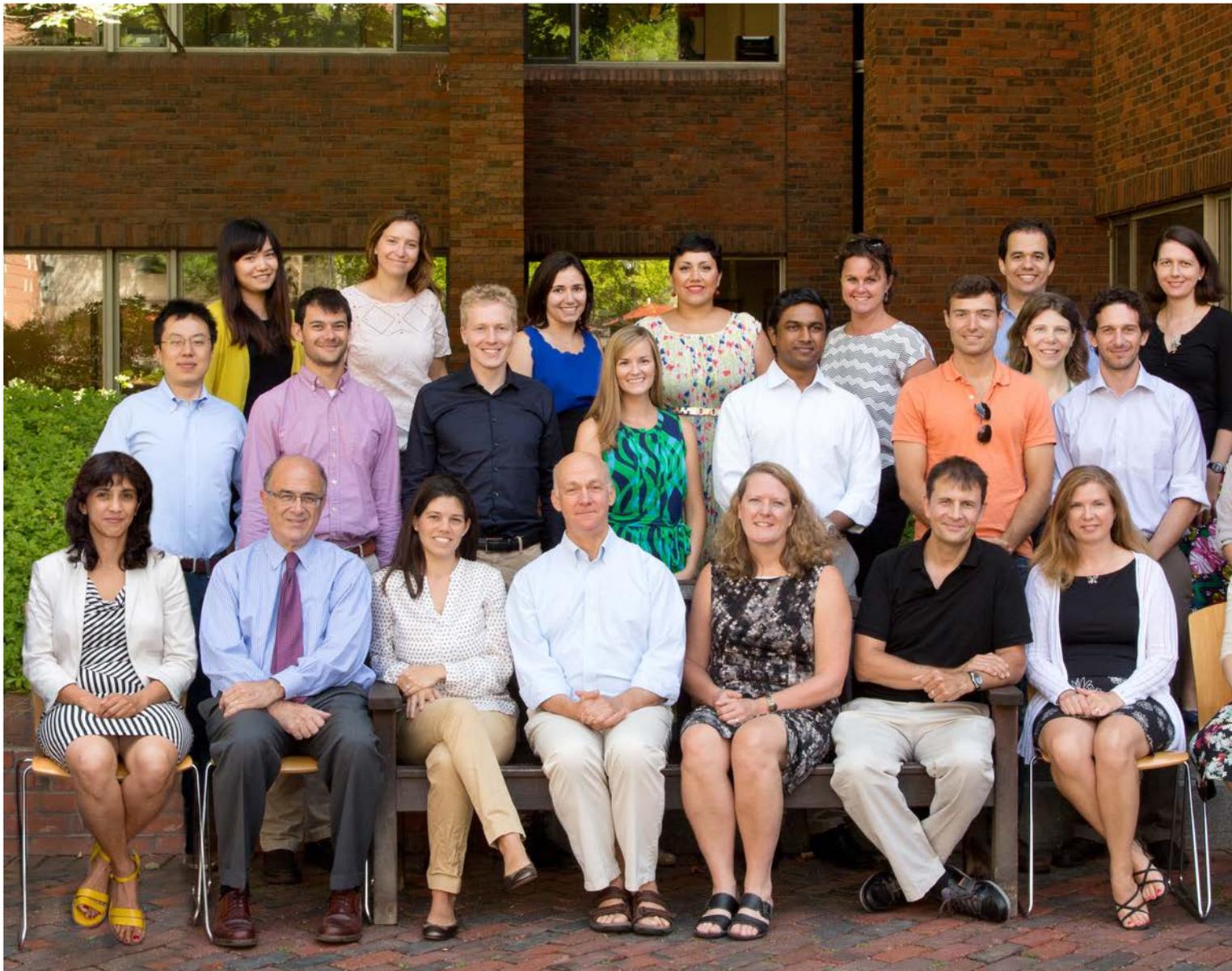
- **Mayukha Karnam** '19, will study “COP21: Gap between assessments and action” with Professor Graham Allison.
- **Jack Kelly** '17, “Increasing Rates of Arctic Ice Loss and the Effect on Melting Methane Clathrates and Permafrosts around the Arctic Basin”
- **Forrest Lewis** '17, “Quantifying the Magnitude of the Kok Effect Through the Growing Season for Dominant Species in a Temperate Forest”
- **Ashton Macfarlane** '17, will work with Professor William (Ned) Friedman on the project “Linking Plant Phenology and Climate Change Through Development.”
- **Ann Opel** '17, “The Effect of Coral Outplant

Sites on Local Fish Communities”

- **Adrienne Propp** '17, will study “The CH4Sat OSSE Project: Motivating satellite observations of methane emissions from oil and gas production” with Professor Steven Wofsy.
- **John Rahill** '18, will study capacitive deionization with carbon nanotubes with Professor Chad Vecitis.
- **Alvaro Valle** '18, will study the performance of redox flow batteries (RFBs) with Professor Michael Aziz.
- **Deng-Tung Wang** '17, “Green Children’s Hospital: Evaluating a synthesis between the green building and the hospital”
- **Miles Wang** '19, will study “Reactive Atmospheric Chemistry Investigated by the Harvard Environ-

mental Chamber” with Professor Scot Martin.

- **Guozhen (Garrett) Wen** '18, “Investigating the Discrepancy Between Empirically Predicted and PILS (Particle into Liquid Sampler) Measured Aerosol Formic Acid in the Atmosphere”
- **Emma Wheeler** '17, will partner with Professor Dustin Tingley to research “What Drives Public and Elite Opinion on Climate Change Politics?”
- **Michael Wong** '18, will work under the mentorship of Professor Alán Aspuru-Guzik to design new photovoltaic materials using machine learning and high-performance computation.
- **Sohyun (Kate) Yoon** '18, will work with Professor Pierre Belanger on the project “Extraction Empire: Sourcing the scales, systems, and states of Canada’s global resource empire.”



**PURSUING
SUSTAINABILITY**
A Guide to the Science and Practice

Pamela Matson
William C. Clark
Krister Andersson



The Sustainability Science Program

Celebrating a decade of use-inspired research

By William C. Clark and Nancy M. Dickson

Sustainable development has emerged as the transcendent challenge of our time. The multiple dimensions of the challenge were captured in the global Sustainable Development Goals adopted by the U.N. last year, but are also reflected in the aspirations and activities of countless corporations, states, communities, and individuals across the globe. Common to these multiple visions is a commitment to fostering poverty reduction and shared prosperity today, but doing so in ways that do not undermine the capacity of future generations to better their own lives. Greenhouse gas emissions and other forms of pollution pose an increasingly clear threat to sustainable development, but so do less immediately obvious trends ranging from the depletion of soils and biodiversity, to the emergence of both new and antibiotic-resistant diseases, to the increasingly unjust distribution of the risks and benefits resulting from the human use of the earth.

Political activism rather than scientific research first brought sustainable development onto the global agenda. But the essential role played by research and innovation in the pursuit of sustainability has never been doubted. And with the turn of the Millennium, a coherent field of sustainability science has emerged, driven (like health science and agricultural science before it) by the goal of producing knowledge that is useful for dealing with the challenges it addresses, and committed to pursuing that goal through integration of perspectives from the natural and social sciences, the humanities, and various forms of practical and traditional knowledge.

Harvard is celebrating this year the 10th anniversary of its own **Sustainability Science Program**, a University-wide effort based at the Harvard Kennedy School and grounded on a generous gift from Italy's Ministry for Environment, Land and Sea. We have co-directed the Program since its inception, jointly with Michael Kremer (Dept. of Economics) and, more recently, Henry Lee (Harvard Kennedy School). The Program serves as a hub for Harvard's multiple sustainability efforts through its fostering of collaborative research, training, and policy outreach.

On the research front, the Sustainability Science Program has supported a range of activities seeking to advance scientific understanding of the tightly coupled social-environmental system. Past work has included studies on water and human health (led by Michael Kremer), integrated use of land and water resources (N. Michele Holbrook), and knowledge systems for sustainability (Bill Clark). More recent initiatives have focused on the interplay of changing climate, hydrology, and land use in Amazonia (led by Paul Moorcroft), governance innovations for pollution control in India (Rohini Pande); decarbonizing the energy sector in China (Henry Lee, Laura Diaz Anadon, and Venkatesh Narayanamurti), and technology innovation and access for sustainability (Laura Diaz Anadon, Kira Matus, Suerie Moon, Alicia Harley, and Gabe Chan).

Training leaders of the next generation of sustainability science has been a central mission of the Program since its inception. The Fellows Program has run an international competition for doctoral, post-doctoral, and mid-career scholars and practitioners who wish to complement their original training with additional exposure to thinking at the frontiers of sustainability science. Those selected are supported to come to Harvard for a year of training and collaborative research. More than 140 fellows from over 30 countries have participated in the Program since 2006. This May over half of those fellows returned to Harvard for a Sustainability Science Symposium featuring their work since leaving Cambridge and providing opportunities to strengthen our already vibrant global network of alumni. The training program for the fellows led to the development of a formal course on the "Science of Sustainable Development" now being taught regularly to Harvard undergraduate and graduate students. It has also been offered as a short course for young professionals and as a distributed graduate seminar simultaneously involving students from multiple universities.

Our work is being conducted jointly with governments, businesses, and NGOs to address important policy questions. We have conducted conferences and workshops with these collaborators, making a special effort to host events in the regions most affected by our findings. To promote outreach that makes program results available to the global policy community, we instituted the Executive Sessions on Grand Challenges of Sustainability, co-hosted by the Program and Venice International University. These sessions brought together key scholars and decision makers from around the world for off-the-record discussions and identification of key research and action needs in the areas of biofuels, water, food security, and industrial pollution. The first of the Grand Challenges sessions launched an effort to prepare a set of authoritative, interdisciplinary introductions to the field of sustainability science. The resulting book, tailored to the needs of students and practitioners, was published this year as *Pursuing Sustainability: A guide to the science and practice* by Pamela Matson (Stanford, and an SSP Program advisor), William Clark (Harvard, and SSP Co-director) and Krister Andersson (Univ. of Colorado, and a former SSP fellow). A second book is in the works, designed for researchers just entering the field of sustainability science.

For further information, visit www.hks.harvard.edu/mrcbg/sustsci



MARTHA STEWART / HARVARD PHOTOGRAPHER



ALICIA HARLEY

Introducing the 2016-18 Environmental Fellows

The Center for the Environment extends a warm welcome to its incoming cohort of Environmental Fellows, who will begin their research appointments at the Center this fall. Fellows work for two years with Harvard faculty members to advance research on a wide variety of environmental topics and strengthen connections across the University's academic disciplines. Fellows also meet twice a month for Fellows dinners, which bring them together with a larger, diverse group of Harvard faculty for discussions on environmental issues. Visit our website, www.environment.harvard.edu, to learn more about the Environmental Fellows program or to apply to join the 2017-19 cohort.

Evan Hepler-Smith is a historian of science who studies the management of data and information in the chemical sciences and chemical regulation. Evan earned an A.B. in



literature from Harvard College in 2006 and a M.A. in history from Princeton University in 2012; he will earn a Ph.D. in history of science from Princeton early this summer. As an

Environmental Fellow, Evan will work with David Jones from the Department of the History of Science and the Department of Global Health and Social Medicine at the Medical School. He will pursue research at the intersection of toxicology, environmental regulation, and information technology, exploring the taken-for-granted systems that mediate access to information about environmental risks and threats. Through interdisciplinary collaborations, Evan aims to illuminate the crucial role of things like meta-data standards and nomenclature schemes in efforts to control the effects of chemicals on human bodies and the environment.

Prineha Narang is a physicist and material scientist interested in the theoretical fundamentals of nanoscale energy transfer. Prineha received her Sc.B. in materials science from Drexel University and a M.S. and Ph.D. in applied physics from the California Institute of Technology (Caltech). Her doctoral thesis focused on understanding light-matter interactions in areas ranging from quantum plasmonics to nitride

optoelectronics. A major challenge and opportunity for energy nanotechnologies is to rationally construct nanoscale devices from



the bottom up that can mimic natural light-harvesting assemblies. As an Environmental Fellow, Prineha will work with Alán Aspuru-Guzik from the Department of Chemistry and Chemical Biology. She plans to investigate the theoretical fundamentals of nanoscale energy transfer and mesoscale dynamics of photosynthesis, at the intersection of quantum optics and chemical physics, for the design of next-generation light-harvesting and energy conversion devices.

Kaighin McColl is a hydrologist who studies the terrestrial water cycle and its coupling with the atmosphere. Kaighin earned a B.E. in environmental engineering and a B.Sc. in applied mathematics from the University of Melbourne in 2009. After



graduating, he worked as a water resources engineer in the private sector, as well as a research assistant at the University of

Melbourne. In 2016 he earned his Ph.D. in civil and environmental engineering from the Massachusetts Institute of Technology. He also contributed to NASA's Soil Moisture Active Passive (SMAP) satellite mission, which measures soil moisture and vegetation properties from space. As an Environmental Fellow, Kaighin will work with Zhiming Kuang from the Department of Earth and Planetary Sciences. He plans to work on interactions between clouds and fluxes of heat and moisture from the land-surface. He will also explore possible causes of a warm bias in weather and climate models over land, which may be related to missing land-atmosphere coupling in models. This work also has applications to water resources management, agriculture, and ecosystem health.

Kelsey Sakimoto is a chemist interested in the sustainable production of fertilizer and beneficial soil microorganisms through

solar energy for use in modern agriculture. Kelsey earned his B.S. in chemical engineering from Yale University in 2012 and a Ph.D. in chemistry from U.C. Berkeley in 2016. As a graduate student, he designed hybrid inorganic-biological organisms capable of



high efficiency conversion of solar energy and carbon dioxide to fuels, food, plastics, and pharmaceutical products. As an Environmental Fellow,

Kelsey will work collaboratively with Pamela Silver of the Harvard Medical School and Daniel Nocera of the Department of Chemistry and Chemical Biology. This interdisciplinary work will pair a photovoltaic "artificial leaf" and synthetically engineered microorganisms to catalyze the sustainable production of biofertilizers via solar energy. Additionally, the designer microorganisms themselves will serve as "smart" soil management agents to guard against over fertilization and detrimental agricultural runoff, as well as work symbiotically with plants and the native soil microbiome.

Daniel Zizzamia is a historian of the American West interested in the intersection of history and the earth sciences in



environmental politics and natural resource policy. Daniel earned a B.A. and M.A. in history from the University of Connecticut, and a Ph.D. in history from Montana State University in 2015. As an Environmental Fellow,

Daniel will work with Ian J. Miller of the Department of History. He plans to develop his dissertation into a book that explores how coal, scientific knowledge, industrial technologies, and religious belief combined to encourage Americans to imagine a West that was not perpetually arid, but rather naturally malleable. This project bridges the gap between scientific inquiry and historical research, and directly pertains to energy and climate policy. He will also begin a project on how the geologic history of North America was crucial to creating America's national parks and promoting western tourism. 

Environment @ Harvard

A sampling of the academic year's events

Ongoing Series Ecological Systems in the Anthropocene

This new series, launched in Spring 2016 by HUCE, explores the future of ecological systems in a world heavily impacted by humans.

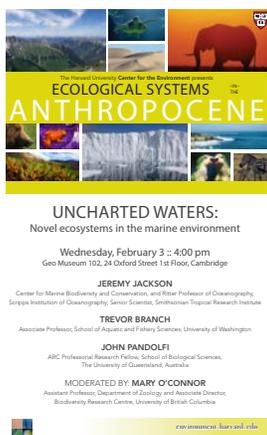
The series kicked off with a panel discussion on “Uncharted Waters: Novel ecosystems in the marine environment” with **Jeremy Jackson**, Ritter Professor Emeritus of Oceanography, Scripps Institution of Oceanography and Senior Scientist, Smithsonian Tropical Research Institute; **Trevor Branch**, Associate Professor, School of Aquatic and Fishery Sciences, University of Washington;

John Pandolfi, ARC Professorial Research Fellow, School of Biological Sciences, The University of Queensland, Australia; and moderator **Mary O'Connor**, Assistant Professor, Department of Zoology and Associate Director, Biodiversity Research Centre, University of British Columbia.

The next installment of the series welcomed **Stephen Jackson**, Director of the Southwest Climate Center, who discussed ecological responses to environmental changes of various kinds, rates, and magnitudes and explored conservation in a post-normal world.

The final lecture of the spring series closed with **Oswaldo Sala**, Wrigley Chair and Foundation Professor, School of Life Sciences and School of Sustainability, Arizona State University. His lecture examined the effects of directional changes in precipitation amount and variability on ecosystems.

The series is organized by HUCE



faculty associate **Elizabeth Wolkovich**, Assistant Professor, Organismic and Evolutionary Biology.

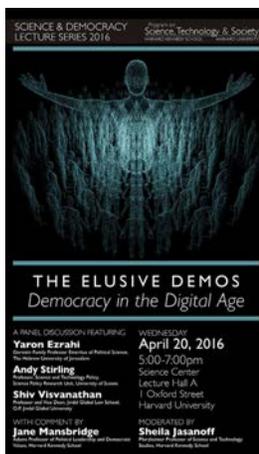
Science & Democracy

Co-sponsored with the Harvard Kennedy School Program on Science, Technology, & Society, this series explores the benefits of scientific/technological breakthroughs and the harmful consequences of inadequately understood developments.

The fall installment of the series welcomed **William D. Nordhaus**, Sterling Professor of Economics at Yale University, for a discussion on the progress and pitfalls of international climate change policy and the adoption of a “club model” to overcome free-riding in relation to global public goods.

The spring installment featured a panel discussion with **Yaron Ezrahi**, Gerstein Family Professor Emeritus of Political Science, The Hebrew University of Jerusalem; **Andy Stirling**, Professor of Science and Technology Policy, Science Policy Research Unit, University of Sussex; **Shiv Visvanathan**, Professor and Vice Dean, Jindal Global Law School, O.P. Jindal Global University; and comment by **Jane Mansbridge**, Professor of Political Leadership and Democratic Values, Harvard Kennedy School, on the realignment of politics and political subjectivities in the digital age.

The Science and Democracy series discussions are moderated by **Sheila Jasanoff**, Pforzheimer Professor of Science and Technology Studies at the Harvard Kennedy School.



Future of Energy

The Future of Energy lecture series brings leaders from business, academia, and government to campus to speak on finding secure, safe, and reliable sources of energy to power the world's economic growth. In November, the series welcomed **Bryony Worthington**, former Shadow Minister for Energy and Climate, UK House of Lords and Founder and Director, Sandbag Climate Campaign, whose lecture focused on “Lessons Learned from the Front Line of Policymaking.”

HUCE Special Lectures HUBweek Event - Coping with Climate Change: How will Boston adapt?

HUCE welcomed panelists **Atyia Martin**, Chief Resilience Officer, City of Boston; **James McCarthy**, Professor of Biological Oceanography, Harvard University; **Sam Spence**, Director of Climate and Environmental Language, City of Boston; **Robert Young**, Director, Program for the Study of Developed Shorelines, Western Carolina University; moderated by **Daniel Schrag**, Director, Harvard University Center for the Environment; **Carl Spector**, Director of Climate and Environmental Planning, City of Boston; and **Robert Young**, Director, Program for the Study of Developed Shorelines, Western Carolina University, to Harvard for a discussion, moderated by HUCE Director, **Daniel Schrag**, on how Boston will manage the impending impacts of climate change.



“Will the Courts Strike Down the President’s Clean Power Plan?” & Special Interview: The Supreme Court and the Clean Power Plan

Last October, Harvard Law School professors **Jody Freeman**, Cox Professor of Law and Director, Environmental Law Program, and **Richard Lazarus**, Aibel Professor of Law, reviewed the various components of President Obama's Clean Power Plan Final Rule and the challenges it faces amid its passage through the courts.

